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August 1975

Development of Some Young Aspen Stands In Arizona

John R. Jones
and
David P. Trujillo

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Abstract

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A substantial apparent range of genotypes and sites was sampled in aspen stands on a 23-year-old mixed conifer burn. No significant regeneration occurred during the summer months following the late June fire, but all plots were heavily stocked with aspen suckers by the end of the third summer. At age 22, dominants averaged from 24 to 40 feet tall (7.3-12.2 meters) on the different plots. Bole volumes ranged from 929 to 4,268 cubic feet/acre (65-299 cubic meters/hectare) and estimated aerial biomass from 25,700 to 113,900 pounds/acre (28,800-127,600 kilograms/hectare). Stocking as well as height differed among clones growing together on the same site.

Keywords: mixed conifers, type conversion, aspen growth, clonal variation, fire, *Populus tremuloides.*

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Development of Some Young Aspen Stands In Arizona

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CONTENTS

Page

Review 1
Study Area 2
Objectives 2
Data Collection 2
Calculations 3
Results 4
    Stocking, Height Growth, and Standing Crop 4
    Growth in Diameter, Basal Area, and Bole Wood 7
    Clonal Comparisons 8
Discussion 9
Literature Cited 10

Development of Some Young Aspen Stands In Arizona

John R. Jones and David P. Trujillo

Quaking aspen (*Populus tremuloides* Michx.) forests occupy somewhat more than a half million acres in Arizona, New Mexico, and the adjacent San Juan Basin of Colorado. In the same region, aspen is also a significant stand constituent in roughly 2½ million acres of conifer forest, which wildfire or heavy cutting can convert to aspen dominance.

The zone of important aspen occurrence—the upper montane and lower subalpine elevations—receives annual precipitation averaging from 15 to 45 inches, but mostly 20 to 30 inches. This zone includes much of the more productive timber-growing land, produces much of the streamflow originating within the region, and constitutes important summer range for deer and elk. Cool summers, scenic diversity, and wildlife make it important to recreationists.

Increasing demands for those commodities and amenities call for increasingly intensive and skillful forest management. That, in turn, requires improved understanding of the biological, ecological, hydrological, and sociological processes involved. This study looks at some biological and ecological aspects of the development of young aspen stands which sprouted in the ashes of a coniferous forest.

REVIEW

Burning or clearcutting aspen forest in the West may result in sucker stands with densities of 14,000 to 110,000 stems per acre. Maximum density is likely the year following disturbance (Sampson 1919, Baker 1925, Smith et al. 1972, Jones 1975); numbers decline gradually thereafter. Losses to disease, browsing, competition, and so forth are not made up by additional suckering, presumably because of the apical dominance and shading effects of the numerous survivors (Maini and Horton 1966, Steneker 1974).

Stand establishment can take a somewhat different course when a coniferous stand with an aspen mixture is clearcut or burned. Regeneration is likely to be substantial the year following disturbance, but the site may be less than fully occupied. Additional suckering may then increase the number of young aspen for several years despite attrition. This pattern has been observed on mixed conifer clearcuttings in Arizona, and was documented by Patton and Avant (1970) on a burn in the Sangre de Cristo Mountains of New Mexico and by Jones and Trujillo (1975) in the White Mountains of Arizona. On the area studied by Patton and Avant, the number of aspen peaked the third year after the fire at 14,550 per acre. Where aspen are fairly numerous in a coniferous stand, the number of aspen suckers following stand destruction may soon approach the number surviving where the parent stand was pure aspen.

Data on aspen growth and stand development in the West are very limited. Baker (1925) published a valuable and broadly informative collection of observations, but his data on growth are largely for stands of age 30 or older from one central Utah watershed. Recent data on development on a 4-year-old aspen clearcut in Arizona (Jones 1975) are from a single site.

Aspen suckers grow much faster than coniferous seedlings: 3-year-old conifers at these elevations in the Southwest commonly are about 3 inches tall (Jones 1971), while 3-year-old aspen are likely to exceed 3 feet (Baker 1925, Jones 1967) and may exceed 10 feet (Jones 1975).

For forest species in general, densities as great as those commonly found in young aspen stands lead either to heavy juvenile mortality or severe growth stagnation. Normally, early differentiation into crown classes results in heavy mortality among overtopped aspen, and allows continued good growth by trees with strong canopy positions (Graham et al. 1963, Pollard 1971, Jones 1975). Stagnation seems to occur in occasional clones, however (fig. 1). Graham et al. (1963) stated that, in

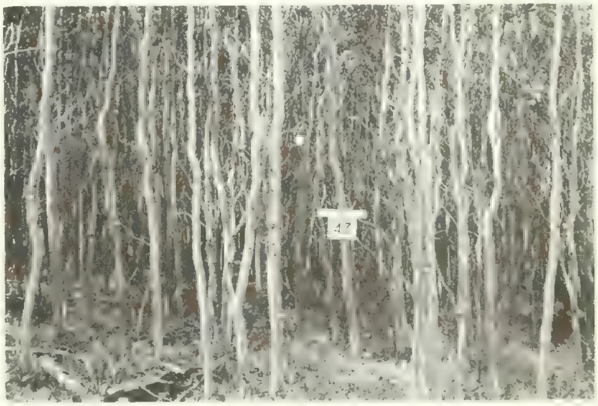

Figure 1.—Clone of stunted 70-year-old aspen showing little sign of natural thinning. Sierra del Don Fernando, Carson National Forest, New Mexico.

Michigan, major natural thinning in young aspen stands commonly occurs at about age 5 and again at about ages 15 and 25. In the Southwest the climate, pathology, and to a degree the growth rates are different, however, and according to Pauley et al. (1963) the aspen differ appreciably genetically from those in the Lake States. Therefore one might expect natural thinning to be timed differently in the Southwest.

STUDY AREA

Between June 23 and July 3, 1951, fire destroyed 19,600 acres of coniferous forest on Escudilla Mountain on the Apache National Forest in east-central Arizona (fig. 2). Most of the forest was virgin. Young aspen stands now occupy much of the burn (fig. 3). The study sites, at 9,300-9,600 feet elevation, were dominated, before burning, by Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and Engelmann spruce (*Picea engelmannii* Parry), but had substantial though variable mixtures of aspen as well as other conifers. Salvage logging began shortly after the fire, and apparently was completed on the study sites before winter.

Judging from temperature stations at similar elevations elsewhere in the White Mountains, average daily July maxima and minima are about 68° and 43°F. For January they are about 39° and 9°F. Average annual precipitation is about 22-23 inches, with perhaps 8 inches falling as monsoon rains in July and August and 10 inches as snow from November through April.

Parent rock is vesicular basalt, which has given rise to very stony silty-loam soils. The plots are on gentle to moderate slopes.

Figure 2.—Mixed conifer forest on unburned flank of Escudilla Mountain, similar to that burned.

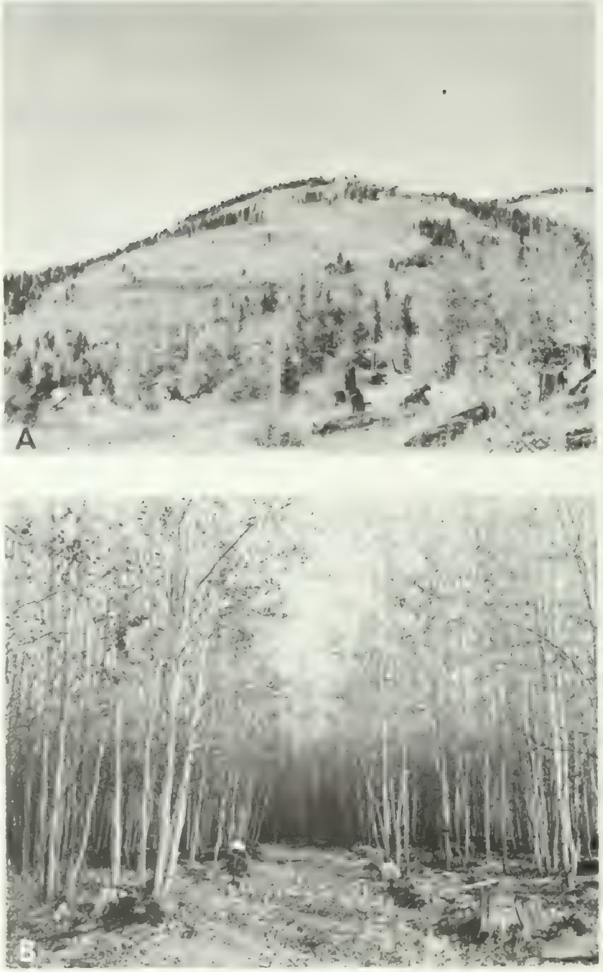

Figure 3.—Young aspen forest on part of the Escudilla Mountain burn: **A**, Perspective view. **B**, Interior view.

OBJECTIVES

The broad purpose was to describe some young aspen stands and their development. Specific objectives were to:

1. Describe stocking, height growth, and standing crop in several 22-year-old stands.
2. Describe the growth in diameter, basal area, and aboveground volume in one of the stands.
3. Compare growth and stocking in different clones sharing the same sites.

DATA COLLECTION

Objective 1

A square 0.01-acre plot was laid out in each of four locations. Each plot had from 62 to 95 live aspens. Each was fairly representative of the stand in which it occurred, except for one constraint: small gaps such as old truck trails, skid roads, and log landings, occur throughout the stands, but none were included in or were immediately adjacent to any plot. Each plot was within a single clone, and no two plots shared the same clone. Plot 1 was located where growth had been notably superior. Plots 2 and 3 showed intermediate height growth. Plot 4 had exceptionally poor growth; its soil was very shallow and stony, and bedrock was exposed nearby.

On each plot, all live and dead trees were numbered and their diameters at breast height (d.b.h., 4.5 feet aboveground) recorded. The crown classes of live trees were also recorded. Dead trees which had broken below breast height were counted but not measured.

On each plot, five randomly selected sample trees from each live crown class were felled. The total height of each sample tree and height to the lowest live branch were recorded. Heights at the end of 1971 and 1972 also were recorded, as defined by bud scars. Below the 1971 height, diameters were taped at eight measured heights along the bole, except that some small, overtopped trees had as few as six diameter measurements. At each point of diameter measurement, a cross section was cut for ring counts.

Rings were counted in the laboratory on all sections except for a few decayed sections from overtopped trees.

Some dead trees were also cut, but the severe growth suppression preceding death made meaningful ring counts impossible.

Objective 2

Plot 2 was chosen for this part of the study. Many of the needed data were acquired for objective 1. In addition, on all sections from live trees, two widths for each ring were measured with a dendrochronograph across a stem diameter subjectively chosen as representative. On all overtopped trees, outer rings were too narrow to measure, even with maximum magnification. On these trees the inner rings, which were larger, were measured individually. The outer rings were measured as a group. Individual ring widths for rings measured as a group were roughly estimated by dividing group width by the number of rings in the group.

Objective 3

Clones in the clonal comparisons were selected because of their noticeable contrasts.

Adjacent to plot 3 and entirely surrounded by the clone occupying plot 3 was another, relatively open, clone of only about 20 ramets. Its bark color was substantially different, the trees were much larger, the wood was distinctly yellow, and the leaves were still green when those on plot 3 were yellow and falling. The site appeared to be the same as on the adjacent plot 3; digging did not reveal any subsurface difference. The four dominant trees in this clone were felled. Measurements and cross sections were taken as on plot 3 for comparison with the dominant sample trees from plot 3. This small clone was designated plot 3A.

Plots 5 and 6 were established a half mile from plot 3, each in a different clone. The site appeared to be homogeneous. As is common, the boundary between these two clones was quite sharp. The clones were distinguished by a notable difference in bark color, tree size, stocking density, and (at the time of sampling) leaf color. The clone with the largest trees also had noticeably closer spacing between trees.

The plots used to characterize these two clones were narrow, linear, nearly parallel, up and down hill, and only 18 to 25 feet apart, to maximize habitat similarity while avoiding interclonal competition. Each plot consisted of five equal subplots in a row. Each subplot was paired with one in the other clone; each was 2.5 milacres. Trees were counted and their d.b.h.'s recorded, by subplot. On each subplot the tree with the largest d.b.h. was felled, its height recorded, and cross sections collected at eight measured heights for ring counts. Heights at the end of 1971 and 1972 were also recorded.

CALCULATIONS

Height-Growth Curves

A height-growth curve was made for each live tree cut on every plot, based on the ring count at each cross section. To assume that a section height marked the end of a year's growth would introduce a small but consistent bias. Therefore it was assumed that height growth had been linear between two cross sections and that each cross section was the midway point in a year's height growth. This reduced the error effect and largely freed it from bias.

The mean curve of height growth was also constructed for each sampled live crown class on each plot.

Objective 1

Basal area was determined for plots 1-4 as the sum of the basal areas of all trees on the plot.

Standing crop was estimated for plots 1-4. The bole volume of each sample tree was taken as the sum of the volumes of its trunk sections including the stump. Volumes per acre were estimated from sample tree volumes. The mass of wood, bark, branches, and summer foliage were estimated from bole measurements using selected equations from Zavitkovski (1971). Branch and foliage weight equations used were those based on diameter at base of live crown. While Zavitkovski did not indicate coefficients of determination for his equations, his data points for the equations used here showed little dispersion around the regression lines, indicating good precision within his sample.

Objective 2

For each year, beginning with 1960 (stand age 9 years), the volume of each sample tree was estimated as the sum of the volume of its segments as calculated from its height-age curve and the width of growth rings. The cross sections had been ovendried to avoid molding in storage, so measurements were conservative. Basal area was reconstructed from growth-ring measurements at breast height. Because past diameters were known only from growth ring measurements, basal areas and volumes in this part of the study were computed only for the stem inside the bark.

Expanding tree volumes to area volumes involved considerations of sampling adequacy for years prior to 1973. Sample-tree selection was random within crown classes for 1973, but in previous years the sample trees did not all belong to their 1973 crown class. Therefore a height-year matrix was made for all the sample trees on plot 2 as a basis for assigning trees to crown classes for years prior to 1973.

Prior to 1960 most of the 21 sample trees were dominant or codominant. Therefore, basal area and standing volumes before 1960 were not estimated.

The sample of overtopped trees is increasingly biased for earlier years because many of the overtopped trees of, say 1965, were dead in 1973 and not suitable for sampling. Therefore the overtopped class is not included in data on the development of basal area, diameter growth, or growth of standing volume.

Objective 3

The height-growth curves and current heights of the dominant trees on plot 3 are compared with those for plot 3A. The comparisons of plots 5 and 6 include number of dead and live trees; heights, height curves, and d.b.h. of dominant trees; and basal area.

RESULTS

Stocking, Height Growth, and Standing Crop

We know too little about young aspen forests in Arizona to say how typical these stands are. The plots are sufficiently different from one another, however, to give us some idea of the variability that can be expected, even within a small climatically homogeneous area.

Stocking

Examination of stumps and down timber indicates that, although aspen was frequent in the parent stands, conifers had predominated on all but plot 4. Stocking data are summarized in table 1. In the 22-year-old postfire stands of plots 1-4, the number of young aspen, alive and dead, averaged 9,400 per acre when disturbance openings are excluded. Of these, 77 percent are still alive.

Many of the broken dead stubs were less than 0.3 inch in diameter near the ground, suggesting that trees dead as long as 15 years were still recognizable for tallying. Therefore, while some suckers certainly died early enough that they had disappeared by 1973, the combined tally of live and dead aspen in table 1 is believed to account for a large majority of all the suckers that came up.

Although the fire burned at the end of June 1951, no sample tree on any plot reached stump height (6 inches) in 1951. We do not even know that any suckers appeared above the soil surface that first summer. Of the 7,250 aspen per acre alive in 1973, 67 percent seem to have emerged in 1952; at least that is when they reached stump height. Another 22 percent first showed up in 1953, and scattered others later. On plot 4, the only plot where aspen outnumbered conifers in the pre-fire overstory, all sample trees, even the overtopped, came up by 1952.

The most important regeneration—all 40 of the sample dominants and codominants on plots 1-4—apparently took place in 1952 and 1953. All sample trees that came up in 1954 or later were in subordinate crown classes by 1973. We do not know when the trees appeared that were dead in 1973. It is reasonable to suppose that many of them came up in 1954 or later, considering the competitive disadvantage of late suckers (Jones 1975).

Almost 70 percent of all trees tallied were dead or overtopped. Only 23 percent were in the dominant and codominant classes, but that 23 percent constitutes 64 percent of the total live and dead basal area.

Table 1.--Number of trees, and basal area, by plot and tree class (per-acre and per-hectare basis)

Tree class	Number of trees				Basal area			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
	- - - - *No./acre* - - - -				- - - - *ft²/acre* - - - -			
Dominant	500	500	500	500	44	38	25	18
Codominant	1,600	1,700	1,900	1,500	87	73	56	35
Intermediate	600	500	1,100	900	20	13	16	10
Overtopped	6,700	4,500	3,200	2,800	75	36	15	13
All live	9,400	7,200	6,700	5,700	226	160	112	76
Dead	1,300	3,000	1,700	2,600	3	7	2	(1)
All trees	10,700	10,200	8,400	8,300	--	--	--	--
	- - - - *No./hectare* - - - -				- - - - *m²/hectare* - - - -			
Dominant	1,235	1,235	1,235	1,235	10.2	8.8	5.7	4.1
Codominant	3,954	4,201	4,695	3,707	20.0	16.7	12.9	8.0
Intermediate	1,483	1,236	2,718	2,224	4.6	3.1	3.6	2.3
Overtopped	16,556	11,119	7,907	6,919	17.3	8.2	3.6	2.9
All live	23,228	17,791	16,555	14,085	52.1	36.8	25.8	17.3
Dead	3,212	7,413	4,201	6,425	.6	1.7	.5	(1)
All trees	26,440	25,204	20,756	20,510	--	--	--	--

[1] Less than 0.5 ft²/acre (0.05 m²/hectare)

Height Growth

Plots 1-4 were numbered in order of dominant height in 1973 (fig. 4). That is also the order of basal area and number of stems. There are no obvious habitat differences between plots 1, 2, and 3 that would seem to account for height differences. The plots were considerably separated, however, and detailed habitat measurements were not made. Plot 4, on the other hand, is notably stonier, and bedrock is exposed in the immediate vicinity.

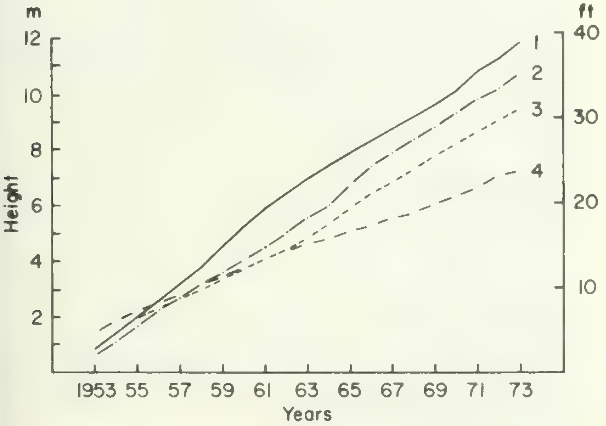

Figure 4.—Height-growth curves for the average dominant tree on plots 1-4.

On plots 1, 2, and 3 the height curves of the current dominant and codominant classes could be differentiated only after several years (fig. 5). In contrast, those for plot 4 were distinct from the beginning. On plots 1 and 2 the overtopped sample trees were more inferior in height and have been inferior longer, than those on plot 3 and particularly plot 4. That may have been due to the heavier stocking and presumably more severe shading on plots 1 and 2, or from site or genetic differences. It probably does not reflect sampling chance; on each plot, the sample mean d.b.h. for each class was quite close to the mean of all trees in the class.

Standing Crop

Under the conditions of site and genotype represented by plots 1-4, bole volumes of live trees ranged from 4,268 cubic feet per acre to 929 cubic feet per acre at age 22 (table 2). From 67 to 79 percent of bole volume was in dominant and codominant trees, despite the large preponderance in number of overtopped trees.

In terms of total bole volume, the mean annual increment of plot 4, the slowest growing, was 42 cubic feet per acre, and of plot 1, the fastest growing, 194 cubic feet per acre.

Zavitkovski's (1971) equations allow us to estimate the ovendry weight of the aboveground parts of trees, and by expansion, of stands (table 3). Dry-weight estimates for boles (wood plus bark) using Zavitkovski's equations (table 3) are close to values determined from bole volumes (table 2), as shown below:

	Bole dry weight, based on— Zavitkovski (1971)	Bole dry weight, based on— Tree volume
	(lb/acre)	
Plot 1	101,745	101,133
Plot 2	57,467	58,842
Plot 3	39,956	42,023
Plot 4	18,499	21,993

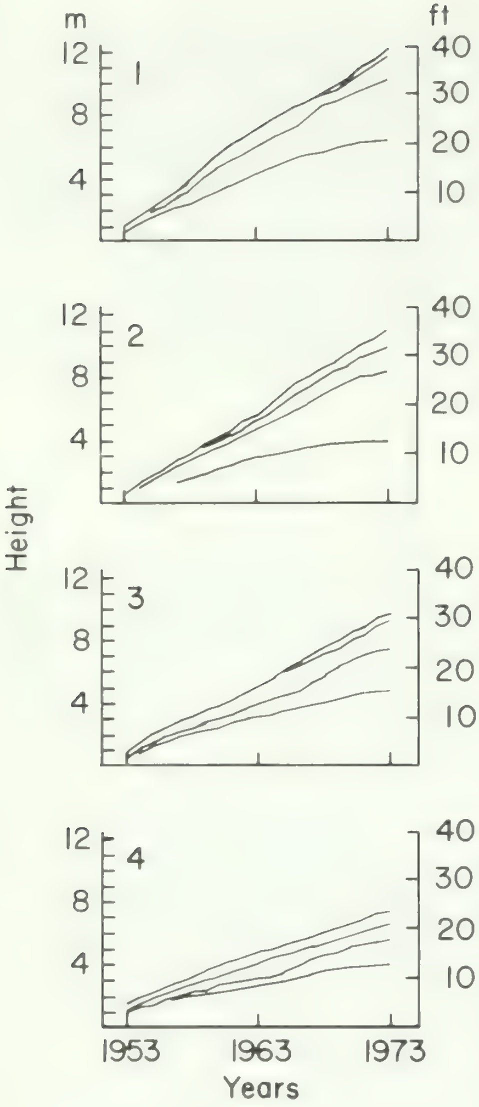

Figure 5.—Height-growth curves for each live crown class, plots 1-4.

Table 2.--Bole volume of live trees, and its distribution among crown classes

Volume and distribution	Plot 1	Plot 2	Plot 3	Plot 4
	- - *ft³/acre (m³/hectare)* - -			
Volume	4,268 (299)	2,486 (174)	1,776 (124)	929 (65)
	- - - - - *Percent* - - - - -			
Distribution:				
Dominant	21	29	24	26
Codominant	46	49	55	50
Intermediate	7	8	12	12
Overtopped	26	14	9	12

Table 3.--Ovendry weight (DW) of live trees, excluding roots, using equations from Zavitkovski (1971)[1]

Tree components	Plot 1	Plot 2	Plot 3	Plot 4
	- - - - - *lb/acre* - - - - -			
Bole wood	83,775	47,234	32,709	15,075
Bole bark	17,970	10,233	7,247	3,424
Branches	9,503	9,148	6,569	5,655
Foliage	2,646	2,310	1,851	1,550
Total	113,894	68,925	48,376	25,704
	- - - - *kg/hectare* - - - -			
Bole wood	93,896	52,953	36,658	16,890
Bole bark	20,140	11,469	8,122	3,837
Branches	10,649	10,251	7,362	6,337
Foliage	2,965	2,589	2,074	1,737
Total	127,650	77,262	54,216	28,801

[1] Equations used are for individual trees. They were applied to each sample tree, and the results expanded to weights per area by crown classes.

$$\log_{10} DW_{kg} =$$

for bole wood--

$$1.028 \log_{10} (\text{d.b.h.}^2_{cm} \times ht_m) - 1.961$$

for bole bark--

$$0.981 \log_{10} (\text{d.b.h.}^2_{cm} \times ht_m) - 2.500$$

for branches--

$$2.716 \log_{10} (\text{diam}_{cm} \text{ at crown base}) - 1.764$$

for foliage--

$$2.242 \log_{10} (\text{diam}_{cm} \text{ at crown base}) - 2.031$$

Values based on bole volumes assume a wood specific gravity of 0.36 for green volume (Brown et al. 1949). Data on the specific gravity of aspen bark are rather variable (Hale 1955, Lamb and Marden 1968, USDA Forest Products Laboratory unpublished); an intermediate value of 0.50 was used here, along with a bark-wood dry-weight ratio of 0.22 based on Zavitkovski (1971).

The dry-weight estimates indicate that production of bole wood and bark is much more strongly influenced by the site-genotype interaction than is the production of branches and leaves (table 4). This is not surprising. Where conditions are limiting, one might expect the crown to have priority in resource allocation.

Table 4.--Weight of tree components, on different plots, as ratios of their weights on plot 4

Tree components	Plot 1	Plot 2	Plot 3	Plot 4
Bole wood	5.56	3.14	2.17	1.00
Bole bark	5.25	2.99	2.12	1.00
Branches	1.68	1.62	1.16	1.00
Foliage	1.71	1.49	1.19	1.00

Growth in Diameter, Basal Area, and Bole Wood

All data in this section are from a single plot, plot 2.

Diameter Growth

The diameter growth of a year's new leader extension is much greater near the base than near the tip. In the second and subsequent years it is similar throughout the internode. Therefore, diameter growth at breast height (fig. 6) is considered here only for the second and subsequent summers after breast height was surpassed. The indicated growth rates are conservative, since they are based on ring measurements of ovendried wood. The trees contributing to the graph for each class were members of that class in 1973. Judging from the individual tree-height curves, the sample trees for all three classes were codominants or dominants in 1961 and earlier.

A conspicuous feature of figure 6 is the marked reduction in diameter growth from 1959 through 1962. Records from the weather station at Alpine, Arizona, 7 miles away and 1,400 feet lower, show no climatic peculiarities for that period. The reduction may have resulted from intensifying competition in the dense sucker stand. The recovery might then reflect an easing of overstory competition as many of the competitors were overtopped and suppressed.

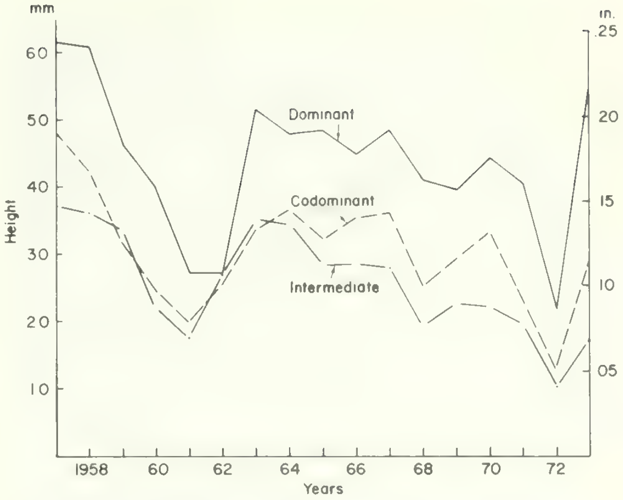

Figure 6.—Diameter growth at breast height, by year, for the dominant, codominant, and intermediate classes on plot 2.

Competition would not seem to explain the abrupt growth reduction in 1972 followed by the strong recovery of 1973. January through April 1972 was almost utterly without precipitation, and our first reaction was that drought accounted for the poorer 1972 growth. But the soil profile was nonetheless moist in spring, recharged by heavy rains the previous October and by the melting of heavy November and December snows. Then, in late May at about the time leafing began, the normal May-June dry season was aborted by substantial showers which were repeated with unprecedented frequency through June. Soil moisture must have been more favorable than usual.

Defoliation can reduce aspen diameter growth. In two Arizona locales, including one in the White Mountains, the senior author noticed occasional light partial defoliation in 1972 by the western tent caterpillar, *Malacosoma californicum* Packard. Only heavy defoliation would have caused such severe growth reduction, however (Hodson 1954, Stelzer 1968). It is not known whether heavy, or any, defoliation occurred on Escudilla Mountain that year.

In almost every year, maximum diameter growth occurred in the upper bole, within the crown. The narrowest rings were laid down in the uppermost meter. Two years or so later, rings at that same cross section typically were wider than anywhere else along the stem. That pattern broke down abruptly in 1971, possibly due to the same factor that caused the marked diameter growth reduction of 1971 and 1972.

Growth of Basal Area and Bole Wood

Growth of basal area and bole wood fluctuated substantially from year to year (fig. 7) with fluctuations in diameter growth (fig. 6). They were graphed as relative growth—the ratio of growth in a given year to growth in the best year. Relative growth was used because the volume and basal area growth data are from ovendried samples, and because it was necessary to omit overtopped trees. Although many of the sample trees had been in stronger crown classes in 1960 than in 1973, this should not markedly affect the graphs, which are based on weighted crown class averages for the years graphed.

There was no apparent tendency for growth of either basal area or bole wood to increase or decline in this stand over the short period included in the study. If such a tendency exists, it was obscured by year-to-year variability, particularly the low points already discussed in the section on **diameter growth.**

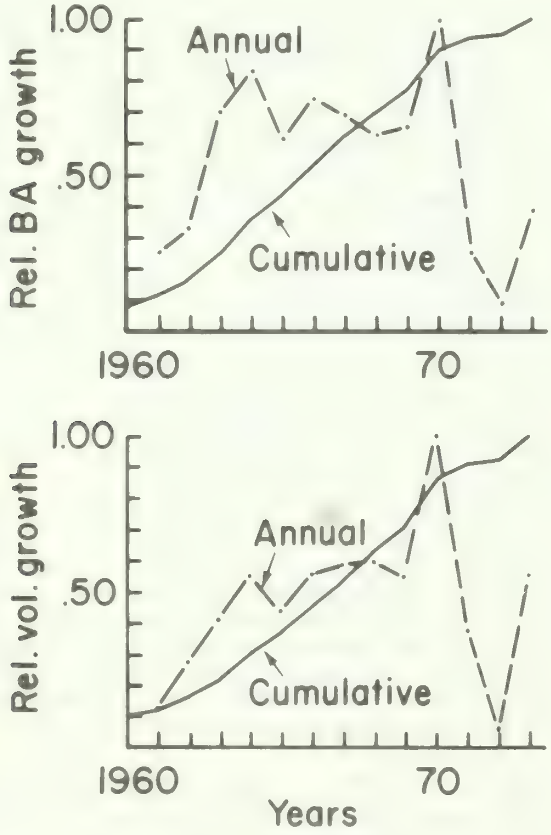

Figure 7.—Relative growth of basal area and bole wood on plot 2. 1.00 represents growth in the year of greatest growth. Data are weighted for the estimated number of trees per acre in the dominant, codominant, and intermediate classes in each of the years graphed. Data from the overtopped class were omitted.

Clonal Comparisons

Because there was no opportunity for randomization in clonal comparisons, probability tests were not used.

Plots 3 and 3A

The contrasts between these two clones are noticeably greater than usual. Heights of dominants on plots 3 and 3A began to diverge rather abruptly about 1957; the divergence continued until 1963 when the dominants on plot 3A averaged more than 23 feet tall while those on plot 3 averaged 16 feet. Since 1963 they have grown at similar rates (fig. 8). Beginning in 1961, the shortest dominant on plot 3A has been taller than the tallest on plot 3. Stocking data were not taken on plot 3A, but its stocking was clearly the least, and the clumpiest, in the study.

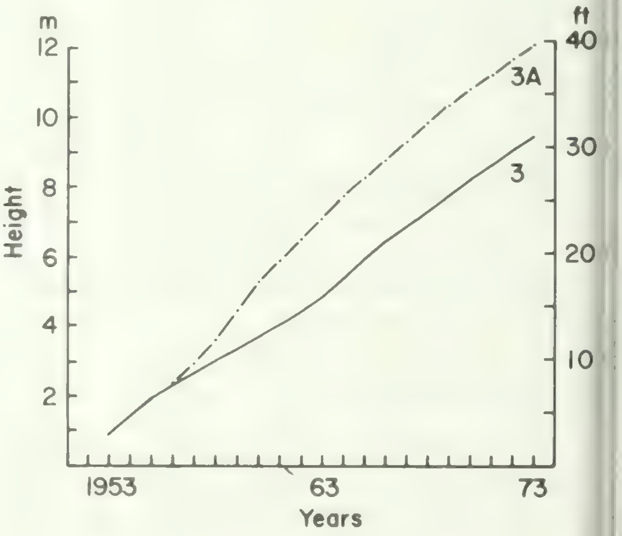

Figure 8.—Height-growth curves for paired clones, plots 3 and 3A.

Plots 5 and 6

The two clones represented by plots 5 and 6, are compared in the tabulation below. For each subplot pair, plot 6 had more live trees and more total trees than plot 5. Furthermore, in every subplot comparison the largest diameter and height were on plot 6. Plot 6 had the greatest basal area on all but one of the subplot pairs, and a 35 percent greater basal area overall.

Character	Plot 5	Plot 6
Number of stems		
Alive	96	139
Dead	54	103
All	150	242
Diameter breast height (max)		
Inches	2.4	3.0
Centimeters	6.1	7.7
Live basal area		
Square feet/acre	90	122
Square meters/hectare	20.7	28.1
Average height of dominants		
Feet	23.6	27.6
Meters	7.20	8.42

Unlike the dominants on plots 3 and 3A, dominants on plots 5 and 6 grew at similar rates until the stand was 16 years old (fig. 9).

Plots 5 and 6 had been the most heavily stocked of any in the study. Plot 5 had 12,000 trees per acre alive and dead, and plot 6 had 19,360 per acre.

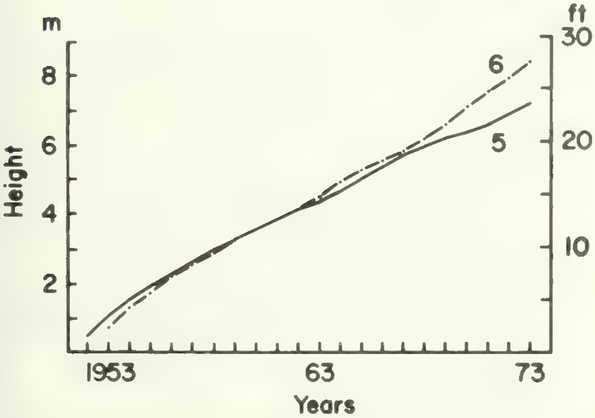

Figure 9.—Height-growth curves for paired clones, plots 5 and 6.

DISCUSSION

Aspen, where frequent in conifer stands, has the ability to reforest sites promptly and heavily following destructive burning. Also, aspen regeneration grows much faster than young conifers on the same sites (Baker 1925, Jones 1971). In this study, dominant aspen varied from 24 to 40 feet tall 23 years after the fire. Where conifers instead of aspen had regenerated the burn, dominants stood only about 5 to 12 feet tall. Mostly, though, where aspen had been absent before the fire, few trees of any species were present after 23 years.

Where a good coniferous seed source was available, coniferous seedlings usually had invaded the young aspen stands in significant numbers.

Our data conform with limited observations (Patton and Avant 1970, Jones and Trujillo 1975) that, if aspen stands follow the burning or clearcutting of mixed conifer forest, new suckering may increase stocking for several years and produce a dense stand. In this instance, however, dominant and codominant trees originated very largely during the first two summers of regeneration.

The apparent absence of aspen regeneration the summer following this late-June fire also conforms with limited earlier data. Sampson (1919), and Baker (1925) did not find significant regeneration on aspen summer clearcuttings until the following year. Further, regeneration was light during the summer immediately following spring clearcutting. Jones (1975) found 1970 regeneration inadequate following clearcutting of an Arizona aspen stand in May and June 1970. In all those cases, stocking was heavy the following year. It may be that the growth inhibitor which mediates apical dominance in aspen and inhibits sucker development (Farmer 1962, Schier 1973, Steneker 1974) begins moving into the roots about the time growth starts in spring, which is before logging or fire usually occurs at these elevations, and persists through that growing season.[2]

Some of the factors influencing aspen height growth may also influence early stocking. The order of dominant heights on plots 1-4 was the same as the order of number of trees. Plots 5 and 6 fell outside that ranking, but of the two, plot 6, with the tallest trees, had many more trees than plot 5 on a seemingly identical habitat.

Plot 3A was the marked exception to the above relationship. Its dominants were the tallest in the study but stocking was relatively light and clumpy.

The long persistence of young, overtopped suckers was unexpected. The height curves of some live overtopped trees indicate they had been overtopped since before 1960. Some had very little foliage. Perhaps they survived on photosynthates from clone-mates via the root connections described by Day (1944), DeByle (1964), and subsequent publications.

Plot 1 had the fastest growing aspens of any plot where volume measurements were made. (The dominants on plot 3A were slightly taller.) The mean annual volume increment (MAI) on plot 1 had been 194 cubic feet/acre, much greater than the potentials indicated for the best Arizona aspen sites, fully stocked, in the recent Forest Survey summary (Green and Setzer 1974). Forest Survey indicates no aspen sites in Arizona with potential MAI greater than 120 cubic feet/acre, and only about 8 percent of Arizona aspen acreage with a potential MAI as high as 85 cubic feet/acre.

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[2] *Personal communication from George A. Schier, Intermountain Forest and Range Experiment Station, Logan, Utah.*

Considering limited data from other Arizona aspen stands (Jones and Trujillo 1975 and unpublished data), height growth on plot 1 was good but not exceptional for Arizona. That on plot 3, with an MAI nearly in the best 8 percent according to Forest Survey, is actually quite mediocre. This suggests that: (1) the aspen yield equations used by Forest Survey are not satisfactory for Arizona, or (2) sampling procedures used by Forest Survey did not adequately describe aspen sites in Arizona.

The equations used by Forest Survey were designed to express **peak** MAI for fully stocked stands. They are from Baker's (1925) yield tables, adapted for use with Jones's (1966) site index table—the existing available sources. Baker's yield tables, however, are based on data from a single Utah watershed. Jones's site index tables were developed largely from Colorado data and may not be as suitable for Arizona as originally thought (Jones and Trujillo 1975). In addition, Forest Survey sampling intensities were chosen to provide a good overall picture of timber supplies. Although suitable for extensive forest types such as ponderosa pine in Arizona, they are weak for restricted types such as aspen.

The differences in height, diameters, and trees per acre of paired clones presumably are hereditary. They may be more conspicuous now than at maturity. Differences in initial sucker numbers will be increasingly obscured by natural thinning. Also, in most cases observed, height differences between paired clones tend to be established in early life, with growth curves later becoming more or less parallel (Jones and Trujillo 1975, and plots 3 and 3A in this study). An 8-foot height difference is more striking in 22-year-old stands than in 80-year-old stands. Nonetheless, associated differences in volume at maturity should be substantial for clones differing by 8 feet in height.

Our knowledge of the growth and yield of aspen in the western United States is inadequate. Small studies like this one only explore the potentials and problems. Definitive studies of growth and yield are needed within a framework of habitat types to provide improved evaluations for planning at regional levels, and for on-site management decisions at local levels.

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Jones, John R., and David P. Trujillo.
1975. Development of some young aspen stands in Arizona. USDA For. Serv. Res. Pap. RM-151, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

A substantial apparent range of genotypes and sites was sampled in aspen stands on a 23-year-old mixed conifer burn. No significant regeneration occurred during the summer months following the late June fire, but all plots were heavily stocked with aspen suckers by the end of the third summer. At age 22, dominants averaged from 24 to 40 feet tall (7.3-12.2 meters) on the different plots. Bole volumes ranged from 929 to 4,268 cubic feet/acre (65-299 cubic meters/hectare) and estimated aerial biomass from 25,700 to 113,900 pounds/acre (28,800-127,600 kilograms/hectare). Stocking as well as height differed among clones growing together on the same site.

Keywords: mixed conifers, type conversion, aspen growth, clonal variation, fire, *Populus tremuloides.*

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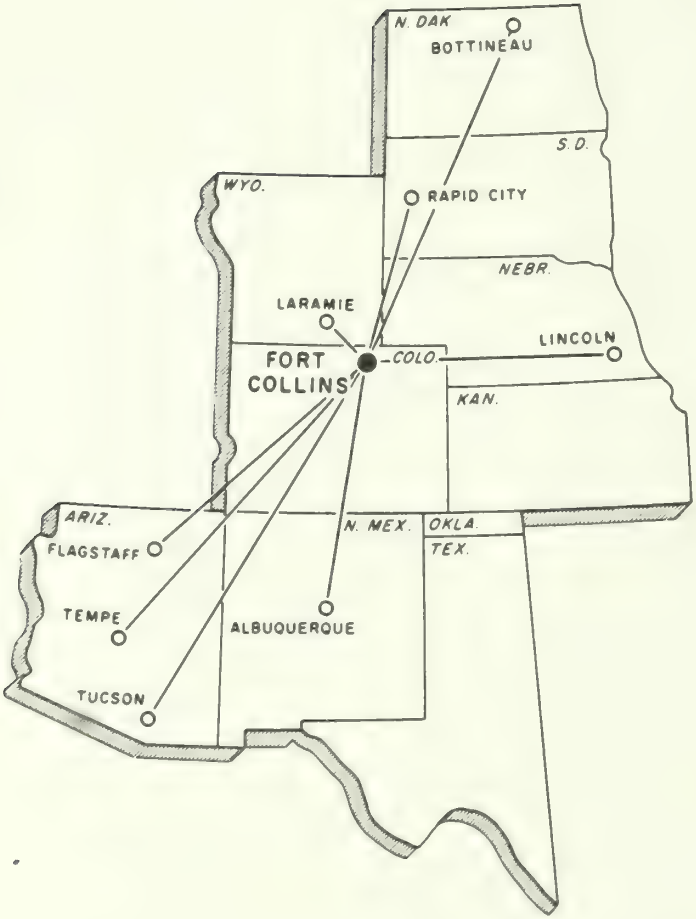
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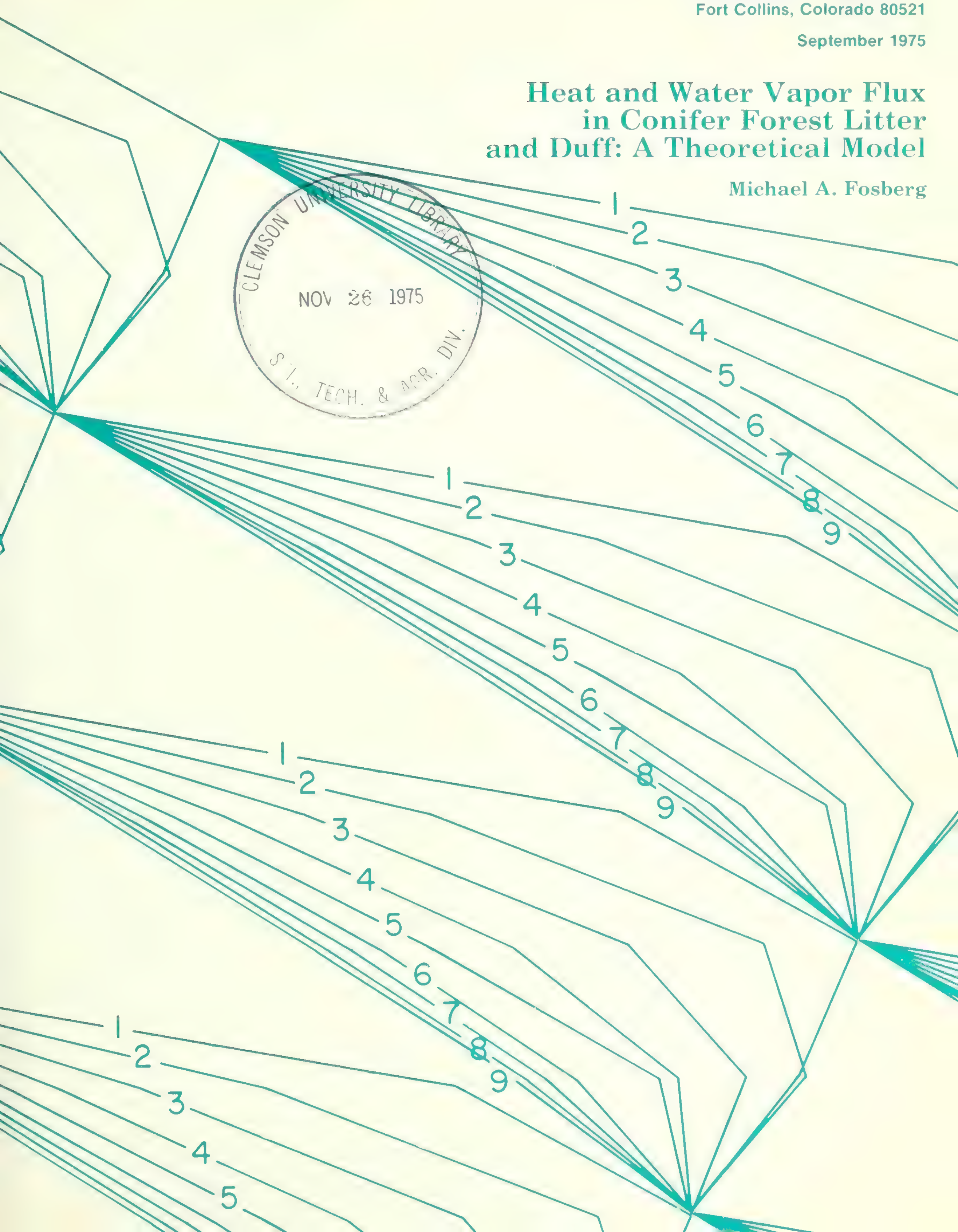
Fort Collins, Colorado 80521

September 1975

Heat and Water Vapor Flux in Conifer Forest Litter and Duff: A Theoretical Model

Michael A. Fosberg



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Abstract

Fosberg, Michael A.

1975. Heat and water vapor flux in conifer forest litter and duff: a theoretical model. USDA For. Serv. Res. Pap. RM-152, 23p. Fort Collins, Colo. 80521.

The model was developed from numerical and analytical solutions of the diffusion forms of the mass continuity equation and the first law of thermodynamics. Analytical solutions provided a functional framework to evaluate nonlinear interactions obtained in the numerical solutions. Dimensional analysis was used to define the relationships between the soil properties used in the model.

Keywords: Soil physics, forest fires, forest fuels.

USDA Forest Service
Research Paper RM-152

September 1975

Heat and Water Vapor Flux in Conifer Forest Litter and Duff: A Theoretical Model[1]

Michael A. Fosberg, Principal Meteorologist
Rocky Mountain Forest and Range Experiment Station[2]

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[1] From a thesis submitted to the Graduate Faculty of Colorado State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University.

Contents

Page
Introduction 1
Analysis of Previous Work 1
Structure of the Model 2
    The Mathematical Model 3
    Idealized Analytical Solutions 6
    Relation of Timelag to Physical Properties 8
    Numerical Solution Methods 9
Results of the Computations 10
    Constant Boundary Conditions 11
    Time-Dependent Boundary Conditions 16
Comparison of Generalized Solutions with Fickian Solutions 16
Conclusions 18
Literature Cited 19
Appendix 21

Heat and Water Vapor Flux in Conifer Forest Litter and Duff: A Theoretical Model

Michael A. Fosberg

Introduction

The uppermost layers of the forest floor are a complex interactive component of the natural water balance. The organic particles found in these layers have water sorption properties that depend on their previous state and on the chemistry and cellular structure of the parent organic material. The physical structure of the layers depends also on the microclimate of the forest stands, as well as the physiology-dependent organic decay rates of the particles.

These particles are rarely in equilibrium with the microenvironment of the soil voids, and almost never in equilibrium with the external environmental stresses imposed by the atmosphere. Organic soil particles respond to the soil void microenvironment more slowly than changes in that void environment. An individual organic soil particle is both a source and sink for water and energy in a complex, dynamic system. Latent and sensible heat exchange and mass conservation of water take place simultaneously and interact between the particles, soil voids, and the external environment. These processes must be accounted for through an interactive model to physically depict the processes in accurate detail.

Wildfire behavior and damage are strongly influenced by the moisture content of the organic forest soils. Prescribed fire for removal of the litter and duff for seedbed preparation, and for hazard reduction through removal of the understory also depends on the litter and duff moisture content. Reliable means of predicting the moisture contents of litter and duff are required for predicting effort required in wildfire control and for safe, beneficial use of prescribed fire.

In this Paper, a theoretical model based on conservation of energy and mass was developed for predicting the moisture content of litter and duff under high moisture stress. The prediction model was obtained by first considering restrictive analytical solutions of simple functions for diffusion of single layers of porous media. These simple solutions for fixed boundary conditions defined a general equation to evaluate timelags from numerical solutions of nonlinear differential equations. The boundary conditions were then relaxed and allowed to vary as small time-dependent step functions in a second analytical solution. This solution defined a more general case, and provided the bases for numerical experiments with the nonlinear equations with variable boundary conditions to evaluate and calibrate the coefficients of the solution. This general solution represented the response of the litter and duff to natural environmental stresses, and provided the functional framework for predicting the moisture and temperature profiles.

Analysis of Previous Work

Soil moisture and heat transfer analysis has traditionally been applied to saturated or partially saturated soils. This emphasis on the presence of liquid-water transfer stems from agricultural needs for moisture in the root zone, and for conservation of impounded water. While the complete processes of heat and mass transfer between soil particles and soil voids and between adjacent voids are qualitatively known, most previous quantitative work has concentrated on the processes associated with liquid water (Chudnovskii 1962, Childs 1969). Under these conditions, the largest mass of soil water is in the soil voids, and the moisture bound within and on the soil particles contributes little to the water balance as sources or sinks of moisture. Because of this emphasis on liquid water, most analytical and theoretical work has been based on a simple Darcy type of flow where the soil structure can be accounted for by simple diffusivity or hydraulic conductivity. The assumption that the particles do not contribute materially to the water and energy budgets breaks down if no liquid water is present, because the total heat content and moisture in the voids is small compared to those in the particles (USDA-FPL 1974, Jackson 1964c).

Studies of soil aeration with nonsorbing porous media demonstrated that the diffusion rates of gases and vapors are a substantial fraction of the molecular diffusion rates in free air. The diffusion of gases in porous media may be as high as 10 percent of that in free air, even with porosities as low as 15 percent (Penman 1940; Taylor 1949; Millington 1959; Currie 1960*a*, 1960*b*, 1961; Millington and Schearer 1971; Ayres *et al.* 1972). For porosities of 70 to 90 percent, the range common to duff and litter, the diffusion rate is 60 to 80 percent of that in the free air. Thus, soils in general and litter and duff horizons in particular do not markedly reduce the gas exchange by their structure.

Experimental determinations of soil-void vapor diffusivities with sorbing materials have produced mixed results; studies by de Jong and Schappert (1972) and Hanks (1958) show agreement with the nonsorbing materials. Jackson (1964*a*, 1964*b*) calculated diffusivities two to three orders of magnitude lower than those found in nonsorbing experiments. Jackson's (1964*c*) steady state experiments provide a clue on how to reconcile this discrepancy. The sorption isotherms indicate that the soil particles contain substantial amounts of water in comparison with that contained in the voids at equilibrium. Jackson assumed that the particles are always in equilibrium with the voids. If the exchange of moisture between the voids and particles is time dependent (lags behind), then use of the equilibrium isotherms to evaluate the diffusivity will underestimate the diffusivity in the voids. If the particles respond very slowly to stress, then the estimate of diffusivity will be very low. Only as their response rate approaches the instantaneous will the equilibrium isotherm technique be valid. Therefore, one must know the response rates of individual particles as well as the bulk diffusivities of the soil matrix to calculate the heat and mass exchange.

Two sets of characteristics of particle behavior need to be defined to properly account for heat and mass transfer between the particles and voids: timelags and equilibrium isotherms. The timelag is defined through the time interval during which a particle will gain or lose heat or moisture from a homogeneous state after a specific change in the environment. The change takes place as an exponential decay to the new equilibrium condition. The timelag is then defined as the time interval required to achieve 1-1/e (approximately 62 percent) of the potential change. Theoretical analysis under laboratory conditions has defined the timelag in terms of particle properties (Byram,[3] Fosberg 1970). This theoretical work was extended to field situations by generalizing the boundary conditions in the solutions (Fosberg 1972, 1973). The equations in Fosberg (1972) provide the basis for moisture exchange in the soil particles, and the equations in Fosberg (1973) do the same for heat exchange. Moisture timelags for many of the litter and duff particles have been analyzed by Nelson (1969), Van Wagner (1969), Fosberg (1970), and Mutch and Gastineau (1970). Data on thermal timelags are far less available. The only compilation for organic materials is in Fosberg (1973). Unfortunately, no data exist for either moisture or thermal timelags of soil particles.

The second set of characteristics that must be known are the equilibrium isotherms for moisture and specific heat of the soil, litter, and duff particles. These isotherms define the boundary conditions required for heat and water exchange. The equilibrium moisture isotherms for soil particles have been compiled by Baver (1956), Jackson (1964*c*), and Miyamoto *et al.* (1972). As with the timelags, there are numerous sources of equilibrium isotherm data for woody materials. The USDA Forest Products Laboratory (1974) has compiled a comprehensive set of tables for commercial woods. Data for fine particles found in litter and duff are presented in Mutch and Gastineau (1970) and Blackmarr (1971). The thermal properties of soil particles are well documented in soil texts (Baver 1956, Chudnovaskii 1962) and those of woody materials in Siau (1971).

Analysis of the soil physics and fuel moisture literature lead directly to a conceptual model of energy and vapor flow in forest litter and duff. The particles respond slowly to changes in the void microenvironment, while the environment of the voids can change rapidly. This process was recognized near the beginning of fuel moisture research. Early papers clearly defined the litter and duff as well aerated (Gast and Stickel 1929) and stated that the particle response lagged behind changes in humidity (Harkness 1939). This slow response of litter and duff particles to liquid water was observed more recently by Clary and Ffolliott (1969). Most of the recent work on duff and litter moisture, particularly that intended for predictive methods, has departed from relations depicting the physical processes, and have concentrated on developing a drought index or build-up index. The approach with the synthetic indices required regression equations to relate the indices to duff and litter (Jarvis and Tucker 1968, Johnson 1968, Muraro and Lawson 1970). While this approach provides easily used tools, the indices are not directly related to duff and litter moisture, and a new set of regressions must be obtained for each site. Van Wagner (1970) approached the prediction problem by a method more closely related to the physical processes. Because he used a mathematical model developed for fixed boundary conditions, his model does not fully depict the physical processes. Van Wagner transformed the model from a constant environment solution to a field solution through a variable timelag. This variable timelag combined both the lag produced by the physical structure and the variations in moisture change produced by a varying environment.

Structure of the Model

Four distinct processes take place simultaneously in the litter and duff system. The organic particles exchange heat and water vapor with the surrounding voids. The exchange rates are determined by (a) the boundary conditions imposed by the temperature and relative humidity in the voids, (b) the excess or deficit of heat and moisture in the particles in comparison to the boundary condition imposed by the void atmosphere, and (c) the rate at which the particles can take up or give off heat and water vapor. The last two processes involve exchange of heat and water vapor between adjacent voids in response to the concentration gradients.

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[3] *Byram, George M. 1963. An analysis of the drying process in forest fuel materials. Paper presented at the 1963 International Symposium on humidity and moisture. Wash. D.C. May 20-23, 1963. 38 p.*

The processes at a given level in the system are illustrated schematically in figure 1. The four corners represent the state variables of heat and vapor in the particles and in the voids. The bold, horizontal double-headed arrows define the dynamic processes of exchange between the particles and the voids. The bold vertical arrows indicate the exchange between adjacent voids. The light arrows and interior cells define the flow of energy and vapor and the interactive process of exchange between the particles and voids. The absolute moisture content and temperature of the voids specify the relative humidity of the voids. The void relative humidity in turn specifies the equilibrium moisture content that the particles would eventually achieve. This equilibrium moisture content represents, then, the environment to which the particles must respond, and is expressed as the boundary condition from the vapor transfer in to or out of the particles.

The transfer of vapor in to or out of a particle depends on the magnitude and direction of the difference between the actual particle moisture content and its equilibrium moisture content. The particles do not respond instantaneously to changes in the environment. The rate of response is expressed through the timelag in a quasi-exponential approach to the equilibrium. The particle timelag contains the information of size, internal moisture diffusivity, and shape of the particle. Heat transfer proceeds in a similar manner.

The temperature and heat content of the voids define the boundary condition imposed on the particles. Like the moisture exchange between the particles and voids, heat transfer depends on the temperature gradient and on the physical characteristics of size, shape, and specific heat. In addition, constraints are imposed by the influence of moisture on the thermal properties and by the second law of thermodynamics because of the large difference in specific heats. The particle moisture content influences the heat exchange through effects on the specific heat and through volumetric changes of the particles. Also, because of the large differences in specific heats and because heat cannot be moved against a temperature gradient, the laws of conservation of heat and mass governing the processes must be supplemented with the second law of thermodynamics.

The Mathematical Model

This descriptive model of heat and vapor transfer in duff and litter is based on two underlying concepts: (1) diffusive exchange between voids is rapid, and (2) exchange between voids and particles is slow, and is the

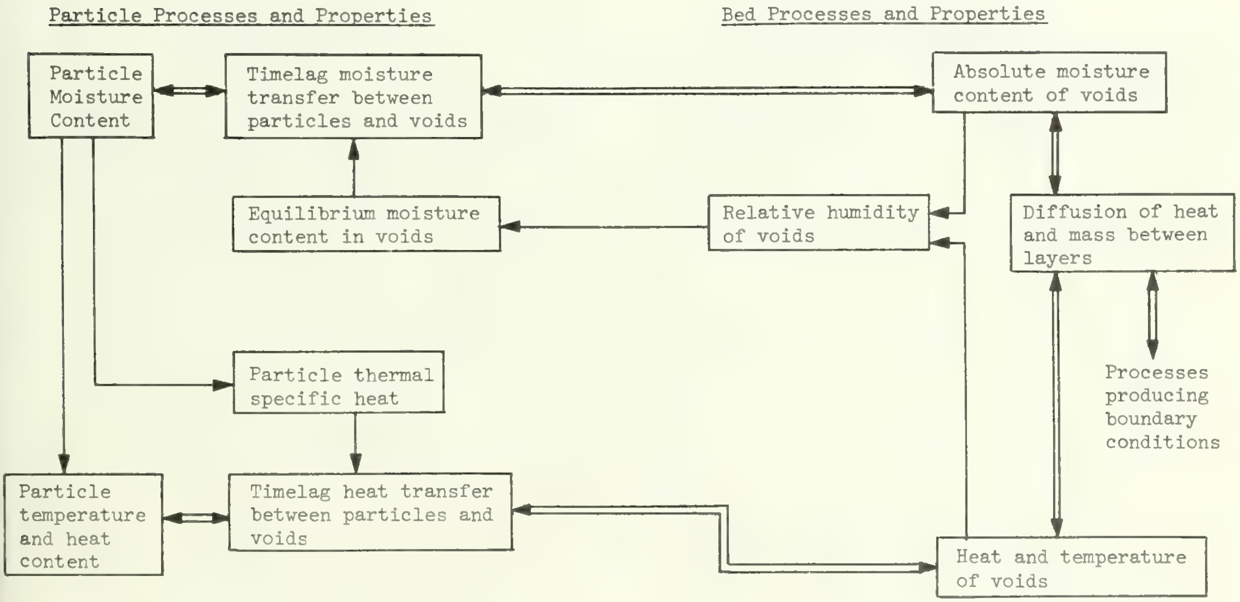
Particle Processes and Properties
Bed Processes and Properties
Particle Moisture Content
Timelag moisture transfer between particles and voids
Absolute moisture content of voids
Equilibrium moisture content in voids
Relative humidity of voids
Diffusion of heat and mass between layers
Particle thermal specific heat
Processes producing boundary conditions
Particle temperature and heat content
Timelag heat transfer between particles and voids
Heat and temperature of voids

Figure 1.—Schematic diagram of heat and mass transfer processes in the internal layers of conifer forest litter and duff.

limiting factor in heat and vapor exchange. A theoretically derived model can now be constructed from these descriptive concepts.

The transport of water vapor through the voids is governed by the conservation of mass equations, where changes in density depend on diffusion of mass and on the vapor taken up or given off by the individual particles. The continuity equation for vertical transport in a horizontally homogeneous layer is:

$$\frac{\partial \rho_v}{\partial t} = \nu \frac{\partial^2 \rho_v}{\partial z^2} + \frac{\partial \nu}{\partial z}\frac{\partial \rho_v}{\partial z} \pm \chi$$

where ρ_v is the density of water vapor in the voids, ν is the molecular diffusivity governing the transport between voids, and χ is the rate of exchange of water vapor between the particles and the voids. The moisture content of the litter and duff particles is expressed on an ovendry gravimetric base. Gain or loss of moisture content by the particles must be transformed to units consistent with those of the continuity equation. The moisture content of the particle is expressed as the mass of water divided by the ovendry mass of the particle, and the vapor density is expressed as the mass of water vapor in the void volume. The particle moisture content is transformed to equivalent vapor density through multiplication by the bulk density of the layer and division by the porosity:

$$m \frac{\rho_B}{\phi} = \rho'_v$$

where m is the particle gravimetric content, ρ_B is the layer bulk density, and ϕ is the porosity. The relationship between particle changes in moisture and the corresponding moisture taken up or given off to the voids is now obtained by differentiation and thus defines the source or sink term χ.

$$\left[\frac{\rho_B}{\phi}\right]\frac{dm}{dt} = \frac{d\rho'_v}{dt} = \chi$$

The changes in particle moisture content produced by environmental stress derived by Fosberg (1972) are:

$$\frac{\delta m}{\Delta m} = 1 - \zeta_m \exp\left[-\frac{t}{\tau_m}\right]$$

where δm is the actual moisture exchange, Δm is the potential exchange if the particle responded instantaneously, ζ is a coefficient reflecting the internal distribution of moisture, τ_m is the particle timelag, and t is the time over which the environmental stress acts. The particle moisture exchange may be differentiated and substituted directly into the continuity equation. Since the continuity equation is nonlinear, it will be solved by finite difference methods; this form of the equation is appropriate provided t is replaced by δt, the finite time step. The continuity equation for water vapor is, therefore:

$$\frac{\partial \rho_v}{\partial t} = \nu \frac{\partial^2 \rho_v}{\partial z^2} + \frac{\partial \nu}{\partial z}\frac{\partial \rho_v}{\partial z} - \chi \qquad [1]$$

where χ is approximated over a small finite interval by

$$\chi = \frac{\delta m \rho_B}{\phi} \qquad [2]$$

and

$$\delta m = m - m_i = \left(m_e - m_i\right)\left(1 - \zeta_m \exp\left(-\frac{\delta t}{\tau_m}\right)\right) \qquad [3]$$

The transfer of heat through the voids is governed by the first law of thermodynamics. Since the particular problem is concerned with a shallow system vertically, the first law may be approximated as

$$c_p \frac{dT}{dt} - \frac{1}{\rho_a}\frac{dp}{dt} \approx c_p \frac{dT}{dt} = s$$

where c_p is the specific heat at constant pressure, T is the temperature, and s is the source or sink of heat provided by the particles. As with the water vapor, the heat is exchanged between voids by diffusion. The first law of thermodynamics is:

$$c_p \frac{\partial T}{\partial t} = c_p k \frac{\partial^2 T}{\partial z^2} + c_p \frac{\partial k}{\partial z}\frac{\partial T}{\partial z} \pm s$$

where k is the molecular diffusivity in the voids.

The thermal source or sink of heat provided by the litter and duff particles is also obtained from the first law of thermodynamics. Since energy must be conserved, any exchange of heat must be equal.

$$\delta H_F = \delta H_a$$

The total heat of the air is:

$$\delta H_a = M_a c_p \delta T_a$$

where H_a is the heat content of the voids, M_a is the mass of air in the voids, and T_a is the void air temperature. Similarly, for the particles:

$$\delta H_F = M_F c_F \delta T_F$$

and the void heat change is:

$$c_p \delta T_a = \frac{M_F c_F \delta T_F}{M_a}$$

Now, by multiplying this expression by a sequence of unity ratios:

$$\delta T_a = \frac{M_F \; c_F \; \delta T_F}{M_a}\left(\frac{V_F}{V_F}\right)\left(\frac{V_v}{V_v}\right)\left(\frac{V_B}{V_B}\right) = \frac{\rho_F}{\rho_a} \; \frac{(1 - \phi)}{\phi} \; c_F \; \delta T_F$$

The heat exchange is expressed in terms of readily available properties. The V's refer to volume and the subscripts F, V, and B represent particle, void, and total bed, respectively.

The dynamic response of temperature changes in the particles is given in Fosberg (1973) and is:

$$\frac{\delta T}{\Delta T} = 1 - \zeta_T \exp \; \frac{-t}{\tau_T}$$

where δT is the actual temperature change, and ΔT is the potential change for an instantaneous response, ζ_T is the internal distribution coefficient, and τ_T is the thermal response time or timelag.

Because $\rho_F \; c_F$ is much greater than $\rho_a \; c_p$, the second law of thermodynamics must also be considered. It is not necessary to quantitatively consider the second law in the numerical solutions, however. If the time step is selected sufficiently small, so that the heat flow from the high temperature to the lower temperature is maintained in the finite difference calculation , it is sufficient to calculate the heat exchange based only on the first law. The equation for temperature change in the voids is:

$$- \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial z^2} + \frac{\partial k}{\partial z}\frac{\partial T}{\partial z} - \frac{s}{c_p} \qquad [4]$$

The temperature change in the voids by exchange with the particles is then

$$s = \delta T_F \frac{\rho_F (1 - \phi) c_F}{\rho_a \; \phi} \qquad [5]$$

and the temperature change in the particles is

$$\delta T_F = T_F - T_{Fi} = \left(T - T_{Fi}\right)\left(1 - \zeta_T \exp\left(\frac{-\delta t}{\tau_T}\right)\right) [6]$$

Equations [1] through [6] defiine the four dynamic processes of heat and vapor change and the two sets of relations between void and particle exchange. The equation of continuity [equation 1] and the first law of thermodynamics [equation 4] define the void-to-void exchange in terms of void properties and gains from or losses to the individual particles. The gain or loss of water vapor by the particles is given by equation [3] and the gain or loss of temperature is given by equation [5]. The interface of mass exchange between equation [1] and equation [3] is given by equation [2]. The conservation of heat exchange with the restriction of preserving the second law of thermodynamics is given in equation [5]. With these six equations, the moisture and temperature profile dynamics are fully defined.

These equations must be supplemented by a set of diagnostic state equations to fully close the system. These diagnostic equations relate the void air thermodynamics properties to the void stresses imposed by relative humidity on the moisture and the heat content of the particles. The boundary condition of moisture transfer is defined as the equilibrium moisture content. This equilibrium moisture content is strongly dependent on relative humidity. Since the temperature and vapor density are known at any given time and point, the equations of state

$$e = \rho_v \; R_v T \qquad [7]$$

can be used to calculate the vapor pressure in the voids. At constant pressure, the saturation vapor pressure is a function of temperature only. The saturation vapor pressure is calculated from the Goff-Gratch formulation presented in the Smithsonian meteorological tables (List 1966) and is reproduced here for completeness. The saturation vapor pressure is

$$\begin{aligned}\log_{10} e_s = {} & 1\ 7.90298 \left(\frac{T_s}{T} - 1\right) \\ & + 5.02808 \log_{10}\left(\frac{T_s}{T}\right) \qquad [8] \\ & - 1.3816 \times 10^{-7}\left(10^{11.344\left(1 - \frac{T}{T_s}\right)} - 1\right) \\ & + 8.1328 \times 10^{-3}\left(10^{-3.4919\left(1 - \frac{T_s}{T}\right)} - 1\right) \\ & + \log_{10} e_{ws}\end{aligned}$$

where T_s is the boiling point temperature (373.16°K) and e_w is the saturation pressure of ordinary water at the boiling point temperature (1.013246×10^3 dynes cm^{-2}). The relative humidity (h) is then specified by:

$$h = \frac{100e}{e_s} \qquad [9]$$

The boundary condition required for vapor flux to and from the particles is expressed by the equilibrium moisture content. Values of the equilibrium moisture content of softwoods as a function of temperature and relative humidity are given in the *Wood*

Handbook (USDA-FPL 1974). Equilibrium isotherms for pine needles were obtained from unpublished results of Blackmarr.[4]

The only other function needed to close the set of equations is the relation for specific heat of the particles. The specific heat according to Siau (1971) is:

$$c_F = \frac{m + 0.324}{1 + m} \text{ cal gm}^{-1} \text{ °C}^{-1} \qquad [10]$$

The diffusion of water vapor or heat through the voids is predicted from Millington and Schearer's (1971) tortuosity factor. They determined that the vapor and thermal diffusivities would be reduced from the free air values by the ratios:

$$\frac{\nu}{\nu_\circ} = \phi^{2x} \qquad [11a]$$

and

$$\frac{k}{k_\circ} = \phi^{2x} \qquad [11b]$$

where the exponent x is defined by the implicit relation

$$\phi^{2x} = 1 - (1 - \phi)^x \qquad [12]$$

If equation [12] is solved for x by relaxation, then the vapor diffusivity ν and thermal diffusivity k in the voids are defined by the values they would have in the free air. These free air values are indicated by the subscript $_\circ$.

These predictive and diagnostic equations are highly interdependent and must be solved simultaneously. Because of the nonlinear character of the basic void diffusion equations, they must be solved numerically in order to obtain valid prediction of duff and litter moisture.

The procedures required to produce meaningful solutions from these equations require a number of separate solutions which are combined at various stages to provide the general models and the associated coefficients. Two distinct models were developed. The first was for heat and vapor flux under constant boundary conditions as might be carried out in a laboratory. This model was obtained first by developing simple analytical solution. This analytical solution was then refined by a series of numerical solutions to refine the analytical coefficients. Similarity solutions were then developed which predicted the laboratory timelags from the physical properties. The numerical values used to develop the similarity relationship came from computer simulations. This model provided four equations. The first two predicted the time-dependent behavior of heat and vapor change in the porous bed, and the second two provided the heat and mass timelags from physical structure.

The second model was developed to transform the laboratory-type solution to field situations where the boundary conditions are continually changing. As in the laboratory model, this model was developed from analytical and numerical solutions. The analytical solution was obtained through the philosophy previously presented in Fosberg (1972) where the structural and environmental influences were separated. Timelags obtained in the first model were then used as a basis for evaluating environmental changes through numerical solutions. This model provided two time-dependent equations to be used with the similarity solution of the first model. Two coefficients of environmental influence were also defined covering heat and vapor flux.

Idealized Analytical Solutions

First, a simplified set of equations was solved analytically. These analytical solutions are gross simplifications of the real world situation. They are useful in that they provide a framework in which to evaluate the numerical solutions, and they define the types of numerical simulations that are required to obtain a prediction system of equations.

The analytical solutions were derived from simplified forms of equations [1] and [4]. In addition, the source and sink of energy or mass were neglected. Thus the analytical solutions represent Fickian diffusion through an inert porous media—one in which the particles respond instantaneously to pore microenvironmental changes. With these initial assumptions, the general form of equations [1] and [4] reduced to

$$\frac{\partial q}{\partial t} = D \frac{\partial^2 q}{\partial z^2} \qquad [13]$$

Here, q represents either the vapor density of equation [1] or the temperature of equation [4], and D is either the vapor or thermal diffusivity. If a nondimensional variable R is defined as

$$R(t,z) = \left(\frac{q(t,z) - q_e(z)}{q_\circ - q_e(z)} \right)$$

then R lies between 0 and 1. The variable $q_e(z)$ represents the final equilbrium state and $q_\circ$ is the initial homogeneous value of q at time 0.

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[4] *Blackmarr, W. H. November 27, 1972, personal correspondence.*

The diffusion equation [13] becomes:

$$D\left[\frac{\partial^2 R}{\partial z^2} - \frac{\partial R}{\partial z}\left(\frac{2\frac{\partial q_e}{\partial z}}{(q_o-q_e)}\right) - \frac{\partial^2 q_e}{\partial z^2}\quad\frac{(R-1)}{(q_o-q_e)}\right] \quad [14]$$

when expressed in nondimensional forms of q. The first derivative of R with respect to z may be eliminated by letting

$$R = Q\ \exp\left(\frac{1}{2}\int 2\ \frac{\frac{\partial q_e}{\partial z}}{(q_o-q_e)}\ dz\right)$$

With this substitution, equation [14] becomes

$$\frac{\partial R}{\partial t} = D\left[\frac{\partial^2 R}{\partial z^2} + R\left(\frac{\partial^2 q_e}{\partial z^2}\,[1-a] + \frac{\left(\frac{\partial q_e}{\partial z}\right)^2}{(q_o-q_e)}\right) + \frac{\frac{\partial^2 q_e}{\partial z^2}}{(q_o-q_e)}\right] \quad [15]$$

when a is defined as

$$a = (q_o-q_e)\ \exp\left(\frac{1}{2}\int 2\ \frac{\frac{\partial q_e}{\partial z}}{(q_o-q_e)}\ dz\right)$$

If this idealized solution is assumed to have fixed boundary conditions for q at the top and bottom, then the q_e profile is linear and the second derivatives of q_e vanish.

This assumption then allows equation [15] to be reduced further to

$$\frac{\partial R}{\partial t} = D\left[\frac{\partial^2 R}{\partial z^2} + R\ \frac{\left(\frac{\partial q_e}{\partial z}\right)^2}{(q_o-q_e)}\right] \quad [16]$$

Equation [16] may now be solved by separation of variables. We let R equal the product of two functions, one dependent only on time and one only on depth,

$$R = T(t)\ Z(z)$$

so that equation [16] is

$$\frac{Z}{D}\frac{\partial T}{\partial t} = T\frac{\partial^2 Z}{\partial z^2} + b^2 TZ \quad [17]$$

where

$$b^2 = \frac{\left(\frac{\partial q_e}{\partial z}\right)^2}{(q_o-q_e)}$$

Equation [17] then becomes

$$\frac{1}{TD}\frac{\partial T}{\partial t} = \frac{1}{Z}\frac{\partial^2 Z}{\partial z^2} + b^2 = -\alpha^2$$

or

$$\frac{1}{T}\frac{\partial T}{\partial t} = -\alpha^2 D \quad [18]$$

and

$$\frac{\partial^2 Z}{\partial z^2} + (b^2 + \alpha^2)\ Z = 0 \quad [19]$$

The solutions of equations [18] and [19] are

$$T = \exp\ (-\alpha^2 Dt)$$

and

$$Z = A\ \exp\ ((b+i\alpha)z) + B\ \exp\ ((b-i\alpha)z)$$

so that

$$R = TZ = \exp(-\alpha^2 Dt)[A\exp((b+i\alpha)z) + B\exp((b-i\alpha)z)]$$

The real part of this solution is

$$R = \exp(-\alpha^2 Dt)\exp(bz)[C_1\ \cos\ \alpha z + C_2\ \sin\ \alpha z] \quad [20]$$

The boundary and initial conditions imposed on equations [20] are

$$R(0,z) = 1$$

$$R(t,0) = 0$$

$$R(t,H) = 0$$

First applying the boundary condition at $z = 0$

$$0 = \exp(-\alpha Dt)C_2$$

and at

$$z = H$$

$$0 = \exp(-\alpha Dt)\ \exp(bH)\ \sin\ \alpha$$

thus

$$\alpha = \frac{n\pi}{H}$$

and

$$R = \sum_{n=1}^{\infty} C_n \exp\left(-\frac{n^2\pi^2}{H^2} Dt\right) \exp(bz) \sin\frac{n\pi}{H} z \quad [21]$$

The general form of the diffusion processes is obtained by integrating R over the depth of the layer to obtain the integral mean value

$$\hat{R} = \frac{1}{H}\int_0^H R dz$$

$$= \frac{\sum_{n=1}^{\infty} C_n \exp\left(-\frac{n^2\pi^2}{H^2} Dt\right) \frac{n\pi}{H^2}\left(1-e^{-bH}\right)}{\left(b^2 + \frac{n^2\pi^2}{H^2}\right)} \quad [22]$$

This integration shows that an exponential approach to equilibrium should be expected. Thus a simplified form of equation [22] is

$$\hat{R} = \zeta \exp\left(-\frac{t}{\tau_B}\right) \quad [23]$$

where τ_B is timelag of the diffusion process. The constant ζ equals 1 since at time zero $\hat{R}$ equals 1. This analytical solution applies only to conditions in which the external environment is held constant and the internal dynamic properties are initially uniform. This solution provides the basis for evaluation of the system dynamics as they would be investigated in the laboratory.

The laboratory type solution is difficult to apply to the field situation since it requires constant boundary conditions. Therefore a second analytical solution is derived which defines the functional form of the dynamics with nonstationary boundary conditions and a nonuniform initial condition. This solution is obtained by allowing the initial quantity to be a function of z. The boundary conditions are held constant over some small arbitrary interval of time. The value of q from the previous solution then becomes the q_o for the new solution, and a new set of boundary conditions is applied.

The solution for this situation proceeds along the same lines as that for the homogeneous case. The nondimensional variable R is now defined as:

$$R(t,z) = \frac{(q(t,z) - q_e(z))}{(q_o(z) - q_e(z))}$$

and is substituted into equation [13]. As in the previous solution, R is redefined as

$$R = Q \exp\left(-\frac{1}{2}\int 2 \frac{\left(\frac{\partial q_o}{\partial z} - \frac{\partial q_e}{\partial z}\right)}{(q_o - q_e)} dz\right)$$

to eliminate the first derivative. Again the general solution is obtained by separation of variables. In this case, the integral for time is taken over δt, an arbitrary time interval.

The boundary and initial condition for R from solution of equation [20] are still valid. Thus the final solution is identical in form to equation [23].

$$\hat{R} = \zeta \exp\left(\frac{\delta t}{\tau}\right)$$

It is desirable to use the τ_B defined in equation [23] in this solution because τ_B can be determined in the laboratory, and the influences of the physical properties of the porous media can be separated from the influence of the environment.

Thus, if τ_B is used:

$$\hat{R} = \zeta \exp\left(\frac{\delta t}{\tau_B}\right) \quad [24]$$

In this case, ζ is not necessarily equal to 1 during the moisture exchange since it expresses the degree of nonhomogeneity when a new set of boundary conditions is applied.

The forms of equations [23] and [24] provide the basis for evaluating the numerical simulation. Neither equation provides the necessary detail to predict theoretically the operational coefficients required for vapor density or temperature flux.

The analytical solution for fixed boundary condition [equation 23] suggests that numerical solutions and laboratory experiments involving structurally homogeneous layers of litter and duff are required to define the timelags. The equations suggest that an exponential approach to equilibrium is to be expected. Since the initial vapor or temperature profiles are not homogeneous, a different response time should be expected for each different set of initial conditions. Thus, if the timelags as derived in the laboratory are to be extended to field applications, then a second coefficient expressing this nonhomogeneous initial state would be required. This step can be accomplished by either allowing the timelag to be environmentally dependent, or by allowing the new coefficient, ζ, to be variable. This paper is based on the more general solutions of a variable homogeneity coefficient with laboratory-derived timelags.

Relation of Timelag to Physical Properties

The analytical solutions presented above predicted an exponential approach to the equilibrium profile. If this process is valid in the more complex physical system found in nature, then the gain or loss of temperature and vapor density can be expressed through timelag determination. This timelag is directly related to the physical structure of litter and duff layers. The analytical solutions showed that the coefficients in the exponent were related to the physical variables of layer thickness and bulk diffusivity.

If nondimensional groups of timelag, bulk or simple diffusivity, and thickness are formed, then a similarity number is defined as:

$$F_1 = \frac{\tau_B D}{H^2} \qquad [25]$$

which is readily recognized as the Fourier number (Gukhman 1965).

The complete model proposed in this paper includes a number of other variables. These are the diffusivity in the voids, and the particle timelag as well as the depth and horizon timelags. Also, since the particles exchange heat and vapor with the voids, the total mass of particles and their volume should also be considered. Three nondimensional groups of variables may be defined. The ratio of the bulk density to particle density—the packing ratio (β)—is one minus the porosity. The second group is the ratio of the system timelag to particle timelag. The third is composed of thickness of the system, the diffusivities in the voids, and a time variable. This time variable was chosen as the particle timelag since the descriptive model suggested this time interval as the critical time variable. The three groups are:

$$(\beta), \left(\frac{\tau_{PM}}{\tau_{BM}}\right), \left(\frac{\nu_B \tau_{PM}}{H^2}\right)$$

for mass exchange and

$$(\beta), \left(\frac{\tau_{PT}}{\tau_{BT}}\right), \left(\frac{k_B \tau_{PT}}{H^2}\right)$$

for heat exchange. These variables form similarity numbers of:

$$F_M = \left(\frac{\tau_{BM}}{\tau_{PM}}\right)\left(\frac{\nu_B \tau_{PM}}{H^2}\right)^{\frac{2}{3}} \beta^{-1} \qquad [26]$$

and

$$F_T = \left(\frac{\tau_{BT}}{\tau_{PT}}\right)\left(\frac{k_B \tau_{PT}}{H^2}\right)^{\frac{2}{3}} \beta^{-1} \qquad [27]$$

The packing ratio has been placed in the denominator of equations [26] and [27], since the timelag should increase as the bed porosity decreases. The Fourier number of the analytical solutions [equation 25] may be similarly expressed for heat and vapor transfer. The Fourier number for heat transfer is:

$$\hat{F}_T = \frac{\tau_{BT} \hat{k}}{H^2} \qquad [28]$$

and for water vapor

$$\hat{F}_M = \frac{\tau_{BM} \hat{\nu}}{H^2} \qquad [29]$$

The hat (ˆ) over the diffusivities in equations [28] and [29] denote the net value of the diffusivity obtained by neglecting the particle effect in diffusion experiments.

If the detailed theoretical results are a more general solution of the physical processes than those from simple diffusions, then the timelags predicted by either method should be the same for a given set of physical conditions.

Numerical Solution Methods

The analytical and similarity functions provided the basis for evaluating numerical solutions and observational data. The complete set of equations [1 through 6] must be solved simultaneously. Equations 1 and 4 are highly nonlinear and therefore must be solved numerically if the full dynamics are to be preserved.

Finite difference schemes must be adopted for both the spatial and temperal derivatives to solve these equations. The philosophy in describing the space derivatives was that certain regions of the system would require very high resolutions, while in others, the dynamic process would be slow and would not be characterized by strong gradients. Techniques utilizing a constant space interval would require the same high resolution in the quiescent regions as that desired in the strong-gradient, rapid-change regions. The finite difference scheme adopted allowed for arbitrarily selected space intervals between each computational point. This preserved the high resolution desired in certain regions, and reduced the total effort required to obtain a particular solution. The particular finite difference stencils adopted for the void to void diffusion are based on the mean value between each computational point. Thus, the first derivative of a scalar quantity (S) at a point i is:

$$\frac{\dfrac{S_{i+1} + S_i}{2} - \dfrac{S_i + S_{i-1}}{2}}{\dfrac{Z_{i-1} + Z_i}{2} - \dfrac{Z_i + Z_{i+1}}{2}}$$

where Z is the depth below the surface. If the computational points are equally spaced, then this scheme reduces to the familiar centered difference method. If the computational points are not equally spaced and the redundant value at i is eliminated, then the derivative is not defined at the point i. The second derivative is defined by the difference between the uncentered first derivatives

$$\frac{(S_{i+1} - S_i)}{(Z_i - Z_{i+1})} = D_u$$

and

$$\frac{(S_i - S_{i-1})}{(Z_{i-1} - Z_i)} = D_D$$

so that the second derivative is:

$$\frac{(D_u - D_D)}{\left(\frac{Z_{i-1} + Z_i}{2} - \frac{Z_{i+1} + Z_i}{2}\right)}$$

This derivative also reduces to the familiar centered second derivative with equally spaced computational points.

The finite difference time step used in this analysis was the Adams-Bashforth Scheme (Lilly 1965):

$$S_{i,t+1} = S_{i,t} + \left(\frac{3}{2}\left(\frac{\Delta S_i}{\Delta t}\right)_t - \frac{1}{2}\left(\frac{\Delta S_i}{\Delta t}\right)_{t-1}\right)\delta t$$

where the subscripts t+1, t, and t−1 refer to the new time, current time, and previous time, separated by the time interval δt. This scheme was chosen because of well defined stability in nonlinear thermofluid dynamic solutions.

The time step δt must be made sufficiently small so that the characters of the continuous equations are preserved with a minimum of distortion. The maximum value of δt is then defined by linear stability criteria of

$$\delta t_{max} < \left.\frac{\delta z_i}{2D_i}\right)_{min}$$

where δz is the distance between computational points and D is the diffusivity of heat or vapor in the void to void exchange.

A second constraint not related to computational stability, must be placed on the magnitude of the time step. This constraint arises because of the large differences between the internal diffusivities of the particles and those in the voids. This constraint is not a mathematical or physical constraint, but is directly related to the resolution obtainable in digital computers and to the range over which the particle homogeneity coefficient is properly defined. If the two differential equations describing the heat and mass processes in the particles are included with those describing bed processes, then the number of computations that must be made becomes extremely large and beyond capabilities of even the largest computers. Computational limits are imposed by the modified analytical solution [equations 3 and 6]. This restriction is covered by ζ defined only over a small range of $\frac{\delta t}{\tau}$. The net effect is to increase stability. This tradeoff increases the number of time steps, but drastically decreases the total number of computations to the point that a net gain is obtained and practical solutions are possible.

Results of the Computations

The physical properties of litter and duff required to carry out the numerical simulations were the depth of the horizon, bulk density, particle density, thermal and moisture timelags of the particles, specific heat of the particles, and the equilibrium moisture isotherms.

The two species for which a complete analysis was carried out were ponderosa pine *(Pinus ponderosa)* and lodgepole pine *(Pinus contorta)*. The particle densities for ponderosa pine were obtained from Brown (1970), and for lodgepole pine through personal correspondence with him.[5] The moisture timelags and equilibrium moisture isotherms of both species for freshly fallen and weathered needles were obtained from Blackmarr through personal correspondence or unpublished research (see footnote 4). The thermal timelags were calculated from the relations developed previously (Fosberg 1973). The specific heat was given by equation [10]. The bulk densities of the horizons were obtained from samples collected on the Manitou and Fraser Experimental Forests of the Rocky Mountain Forest and Range Experiment Station, and on the Pingree Park Campus of Colorado State University. The ponderosa pine data came only from the Manitou Experimental Forest, while the lodgepole pine data came from all three areas. Data used in the simulations are summarized in table 1.

These data are supplemented through arbitrarily chosen variations for each physical property. Each of three physical variables—depths, bulk density, and particle timelag—were systematically varied over a large range of conditions while the others were held constant. The depths were selected as 1, 3, 4, 6, and 8 cm. The selected particle timelags were 3,600 seconds, 7,200 seconds, and the measured 4,608 seconds. While bulk densities of litter are mostly

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[5] *Brown, J. K. October 11, 1972, personal correspondence.*

Table 1.--Physical properties of duff and litter horizons

Horizon	Particle timelags (sec.)		Density (gm cm^{-3})	
	Moisture (τ_M)	Thermal (τ_T)	Particle (ρ_P)	Bed bulk (ρ_B)
		Ponderosa Pine		
Litter A_{oo}				
Freshly fallen needles	14,760	0.12	0.51	0.08
Weathered needles	4,608	.11	.47	.08
Duff A_o	--	--	.47	.26
		Lodgepole Pine		
Litter A_{oo}				
Freshly fallen needles	63,000	.10	.56	.09
Weathered needles	3,636	.10	.56	.09
Duff$_o$	--	--	.56	.36

in the range of 0.06 to 0.1 gm/cm^3, the mean value of 0.08 gm/cm^3 was supplemented with bulk densities 0.01, 0.02, and 0.03 gm/cm^3 to provide a larger range of values to evaluate the similarity numbers.

The individual computer simulations using equations [1] through [12] for a particular value of particle and bed properties were evaluated through the characteristics provided by the analytical solutions [equations 23 and 24], and by the similarity relations predicted by equations [26] and [29].

The first set of simulation results applies to a constant environment. These simulated results defined the timelag characteristics and provided the functions to predict them from observations of the physical structure.

The second set of simulation results utilizes the predicted constant responses and applies them to prediction of heat and moisture response with time-dependent boundary conditions. This second set of results provides the framework for field prediction.

Constant Boundary Conditions

The numerical simulations of these conditions were conducted under the conditions of an initially homogeneous moisture and temperature. At an arbitrary time zero, an arbitrary step change of either relative humidity or temperature was imposed while the other boundary was held at its original value. The step change in the boundary condition then set up a time-dependent process from the initial homogeneous state to one in which the final equilibrium profile was a linear function with depth. The time-dependent approach to the equilibrium could then be used to determine the timelag of the complete system. As examples, several of the simulations for moisture exchange are shown here to illustrate the details of the nonlinear solutions.

The first set of examples is for isothermal conditions. Boundary conditions were set at 20 percent relative humidity at the surface, and the initial homogeneous void relative humidity was 80 percent. The temperature was 300 K. Particle and bed properties were defined by weathered ponderosa pine litter. The depths of the two horizons were arbitrarily selected as 3 and 4 cm (reasonable values for stands of basal area in the 15 to 20 m^2/hectare range along Colorado's east slope).

Initial moisture properties were used to evaluate the timelags. The integral particle moisture content for the two examples (fig. 2) follows the expected exponential decay. The 3-cm-thick layer had a timelag of

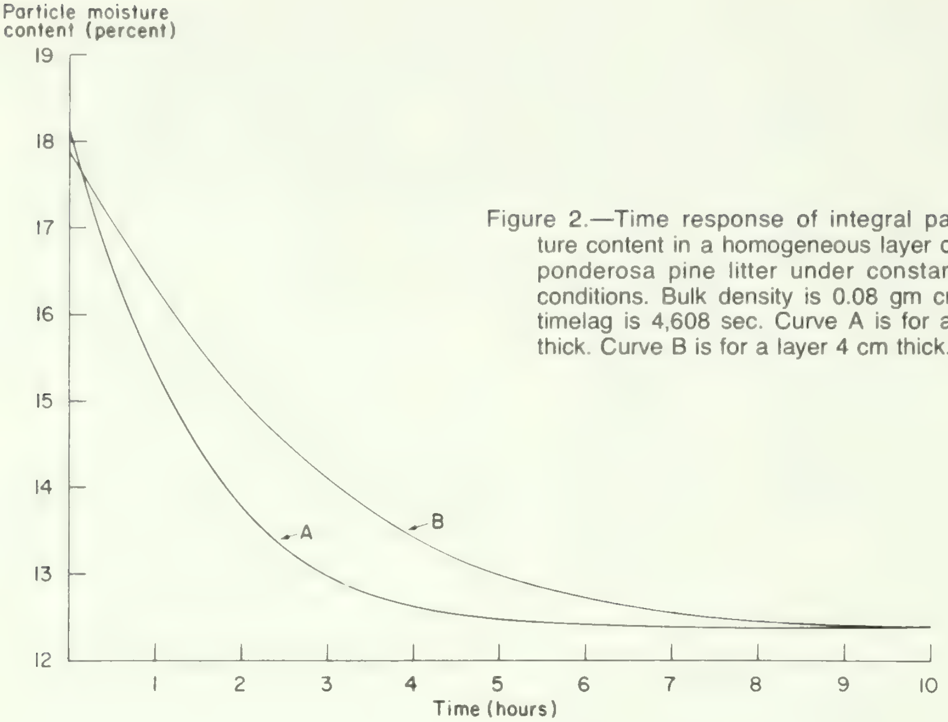


Figure 2.—Time response of integral particle moisture content in a homogeneous layer of weathered ponderosa pine litter under constant boundary conditions. Bulk density is 0.08 gm cm^{-3}. Particle timelag is 4,608 sec. Curve A is for a layer 3 cm thick. Curve B is for a layer 4 cm thick.

4,248 seconds while the 4-cm layer had a timelag of 7,560 seconds. The integral of void vapor density (fig. 3) for the two cases also showed the exponential decay, and had timelags nearly identical to those for particle moisture content. Void vapor density was chosen to represent the moisture transport since the

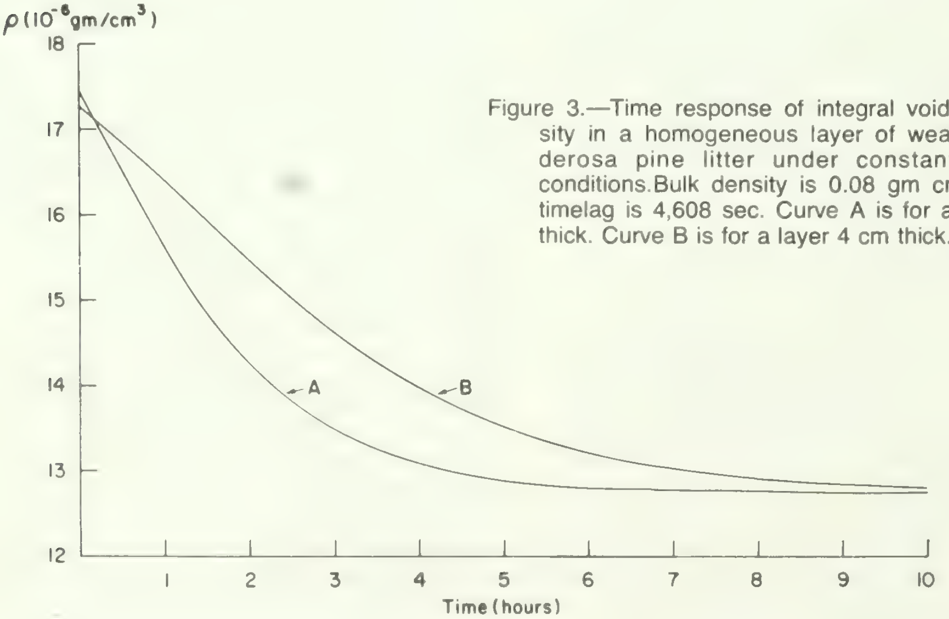


Figure 3.—Time response of integral void vapor density in a homogeneous layer of weathered ponderosa pine litter under constant boundary conditions. Bulk density is 0.08 gm cm^{-3}. Particle timelag is 4,608 sec. Curve A is for a layer 3 cm thick. Curve B is for a layer 4 cm thick.

quilibrium moisture content of the particles is a non-inear function of relative humidity, and because elative humidity is strongly dependent on tempera-ure. Void relative humidity profiles for the two xamples (fig. 4) decayed rapidly to the linear equi-ibrium profile. The particle moisture content profiles fig. 5) can be predicted from the void vapor density and the temperature, since the vapor density and the moisture content approach equilibrium at the same rate.

Temperature in the duff and litter layer changed much more rapidly than moisture. The integral temperature change over time also approached equilibrium exponentially (fig. 6). Surface boundary conditions for the temperature experiments were 290, 296, 305, and

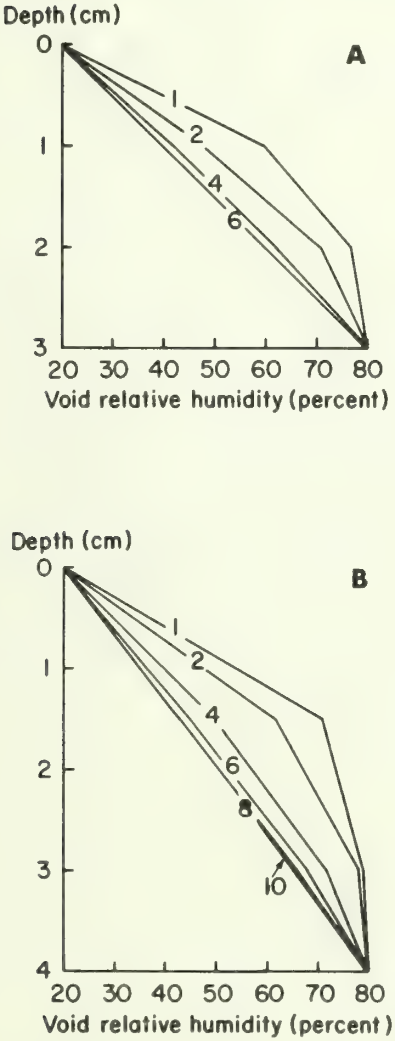


Figure 4.—Profiles of void relative humidity for weathered ponderosa pine litter under constant boundary conditions. Bulk density is 0.08 gm cm^{-3}. Particle timelag is 4,608 sec. Numbers on lines indicate hours since beginning of solution. **A** is for a layer 3 cm thick; **B** is for a layer 4 cm thick.

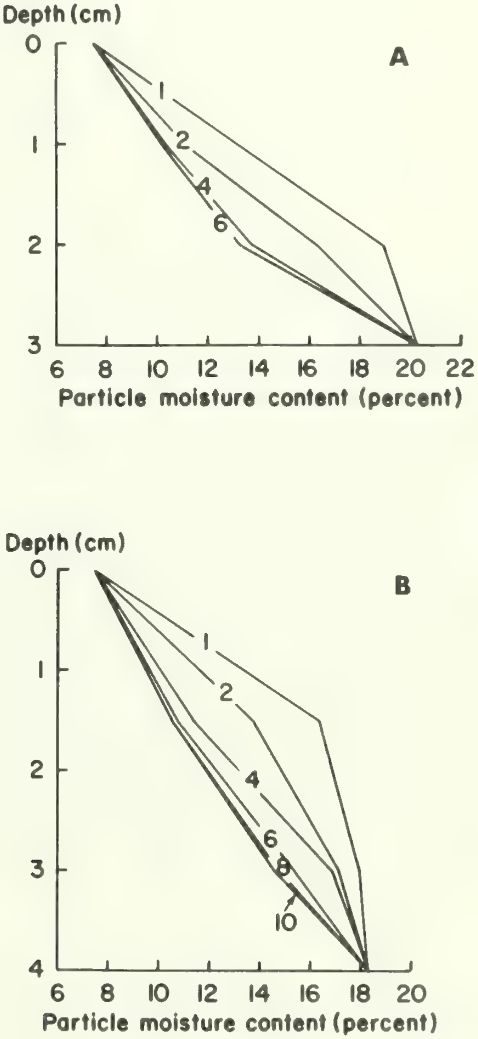


Figure 5.—Profiles of particle moisture content for weathered ponderosa pine litter under constant boundary conditions. Bulk density is 0.08 gm cm^{-3}. Particle timelag is 4,608 sec. Numbers on lines indicate hours since beginning of solution. **A** is for a layer 3 cm thick; **B** is for a layer 4 cm thick.

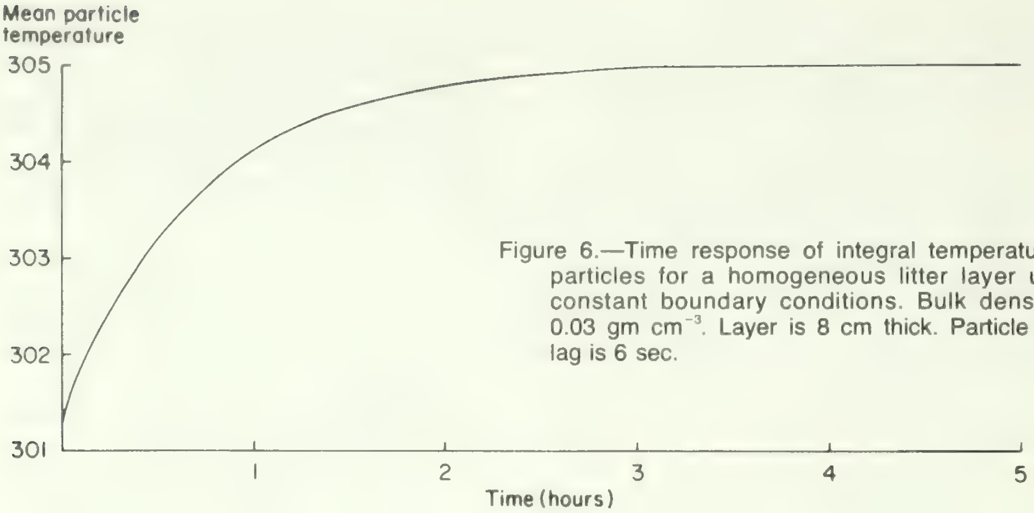


Figure 6.—Time response of integral temperature of particles for a homogeneous litter layer under constant boundary conditions. Bulk density is 0.03 gm cm^{-3}. Layer is 8 cm thick. Particle timelag is 6 sec.

310 K. The initial temperatures were 300 K. Initial and boundary condition relative humidities were 20 percent. Profiles of temperature (fig. 7) behaved similarly to those for vapor density in that their equilibrium profiles were linear. When both moisture and temperature boundary condition changes were imposed, the vapor density profiles still decayed to the linear equilibrium profile (fig. 8). The relative humidity boundary condition was 20 percent and the temperature boundary condition was 310 K. Initial conditions were 80 percent relative humidity and 300 K. The internal maximum of vapor density represents the thermally driven moisture flux. Thus, the conservative nature of temperature and vapor density provides a more stable basis for predicting moisture content than methods based on relative humidity.

The individual results of the 25 simulations where each bed and particle property was systematically varied were combined by the similarity results defined by equations [26] and [27]. These similarity relations provided the basis for predicting the horizon timelags from the physical properties of particles and bed. The vapor density relationship was:

$$F_M = 196 = \frac{\tau_{BM} \, \nu_{BM}^{\frac{2}{3}}}{H^{\frac{4}{3}} \, \tau_{PM}^{\frac{1}{3}} \, (1-\phi)} \qquad [30]$$

and is graphically shown in figure 9. Similarly the relationship for heat transfer is

$$F_T = 309 = \frac{\tau_{BT} \, k_{BT}^{\frac{2}{3}}}{H^{\frac{4}{3}} \, \tau_{PT}^{\frac{1}{3}} \, (1-\phi)} \qquad [31]$$

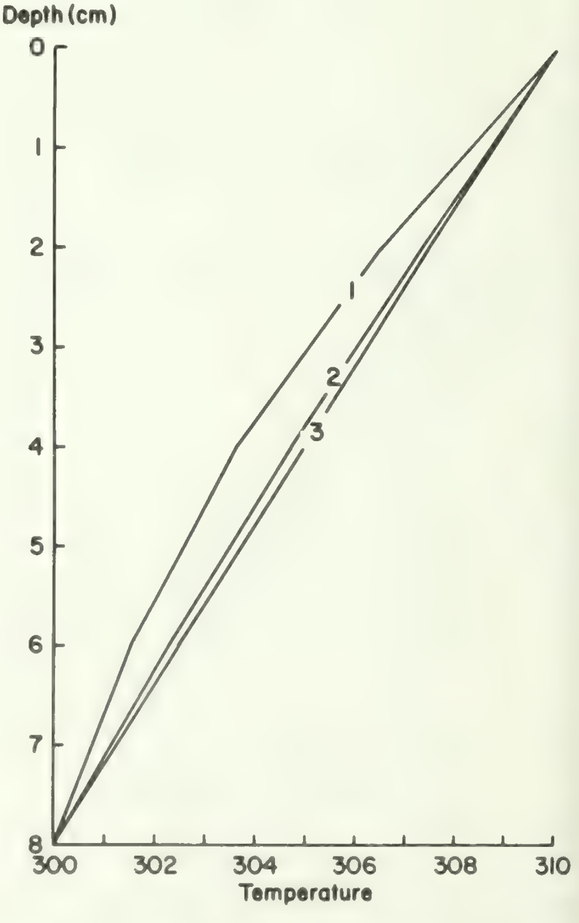
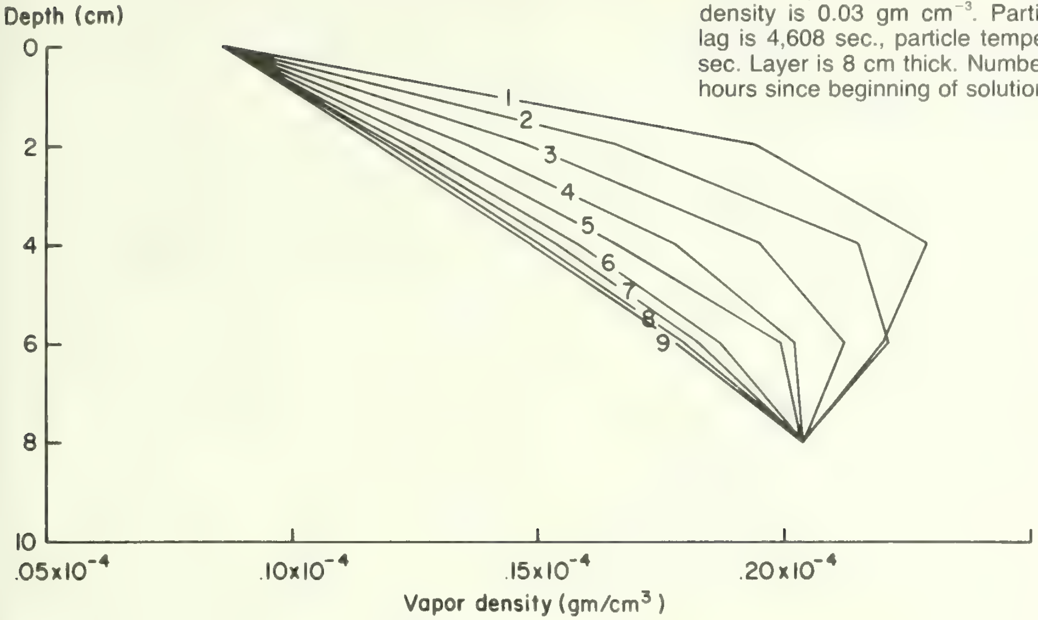


Figure 7.—Profiles of particle temperature for homogeneous litter layer under constant boundary conditions. Bulk density is 0.03 gm cm^{-3}. Layer is 8 cm thick; particle timelag is 6 sec. Numbers on lines indicate hours since beginning of solution.

Figure 8.—Profiles of vapor density for homogeneous litter layer under constant boundary conditions with temperature and humidity stress. Bulk density is 0.03 gm cm^{-3}. Particle moisture timelag is 4,608 sec., particle temperature timelag is 6 sec. Layer is 8 cm thick. Numbers on lines indicate hours since beginning of solution.



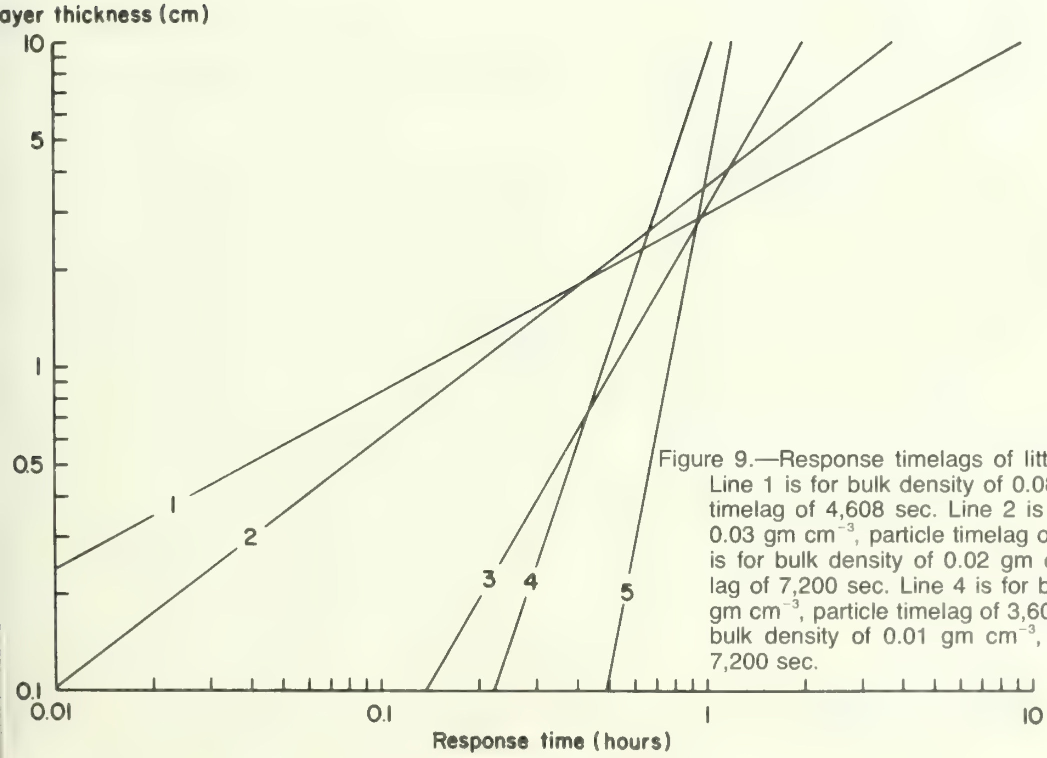


Figure 9.—Response timelags of litter and duff layers. Line 1 is for bulk density of 0.08 gm cm^{-3}, particle timelag of 4,608 sec. Line 2 is for bulk density of 0.03 gm cm^{-3}, particle timelag of 7,200 sec. Line 3 is for bulk density of 0.02 gm cm^{-3}, particle timelag of 7,200 sec. Line 4 is for bulk density of 0.01 gm cm^{-3}, particle timelag of 3,600 sec. Line 5 is for bulk density of 0.01 gm cm^{-3}, particle timelag of 7,200 sec.

The similarity numbers of equations [30] and [31] are averages of the individual simulations. The range of the similarity numbers was 20 percent of the mean for mass transfer and 10 percent for heat transfer. These two similarity relations provided the basis for calculating the moisture and temperature timelags under constant or laboratory conditions.

Time-Dependent Boundary Conditions

The natural environment rarely provides constant boundary conditions. More typically, the boundary conditions are continuously changing temperatures and humidities. Functions must therefore be established for these variations under which the horizons do not reach an equilibrium state. As with the constant environment case, the analytical solutions provide the functional framework for evaluation of numerical solutions. Laboratory and field solutions differ only by a linear multiplier of the exponential terms. This linear coefficient reflects the inhomogeneity of the initial conditions. The coefficient ζ of equation [24] would be unity under constant boundary conditions, but will be different from unity under nearly all field conditions.

The time-dependent boundary conditions were defined by step changes of arbitrary duration and arbitrary magnitude. These changes established a nonhomogeneous interval profile. The integral vapor density (fig. 10) and the integral temperature (fig. 11) change over time show two marked characteristics. The responses of the layers are much more rapid when they start from the nonhomogeneous profile than when they start from the homogeneous profile. This difference can be interpreted either as a change in the timelag or as enhanced transport due to larger gradients. Because the timelag was defined in terms of physical properties, the second interpretation is preferred. This latter interpretation has the advantage that dynamic and physical characteristics are separated in the functions.

The coefficient ζ of equation [24] then must be defined for the heat and mass transfers. This was accomplished by calculating the actual change in vapor density or temperature, the potential change in vapor density or temperature, and using the timelags defined from the constant boundary condition simulation. This ζ is:

$$\zeta = \frac{1 - \frac{\delta S}{\Delta S}}{\exp - \frac{t_d}{\tau}}$$

where δS is the actual change of the scalar quantity, ΔS is the potential change, and t_d is the duration of the pulse.

The homogeneity coefficient for mass transfer is 0.42 and for heat transfer is 0.755. No variation of the coeffiicient was found in the simulation used to determine these values. Variation probably does exist and would be found if more simulation or field experiments are conducted.

Comparison of Generalized Solutions with Fickian Solutions

Bulk diffusivities of the horizons can be used to validate the theoretical predictions. These bulk diffusivities can be calculated from the two pairs of similarity equations. By solving equations [29] and [30] for τ_{BM} and equations [27] and [31] for τ_{BT}, the bulk vapor diffusivity $\hat{\nu}$ and thermal diffusivity $\hat{k}$ can be calculated. The effective vapor diffusivity is:

$$\hat{\nu} = \frac{0.18\ (H\ \nu_B)^{\frac{2}{3}}}{196\ \tau_{PM}^{\frac{1}{3}}\ \beta}$$

and the effective thermal diffusivity is:

$$\hat{k} = \frac{0.14\ (H\ k_B)^{\frac{2}{3}}}{309\ \tau_{PT}^{\frac{1}{3}}\ \beta}$$

The coefficients 0.18 and 0.14 are taken from Fosberg (1972, 1973).

The vapor diffusivity for the example in figures 2 through 5 is:

$$3.1 \times 10^{-4}\ \mathrm{cm}^2/\mathrm{sec}.$$

The thermal diffusivity for the temperature change of figure 6 is:

$$5.7 \times 10^{-3}\ \mathrm{cm}^2/\mathrm{sec}.$$

These bulk diffusivities compare well with experimental values based on equilibrium solutions (Lettau 1954; Jackson 1964*a*, 1964*b*, 1964*c*).

Reported moisture response rates for litter and duff have typically been very slow. Johnson's (1968) analysis of field data gives timelags an order of magnitude greater than reported here. Since Van Wagner (1970) used the timelag as the environment dependent variable, it is difficult to determine the exact magni-

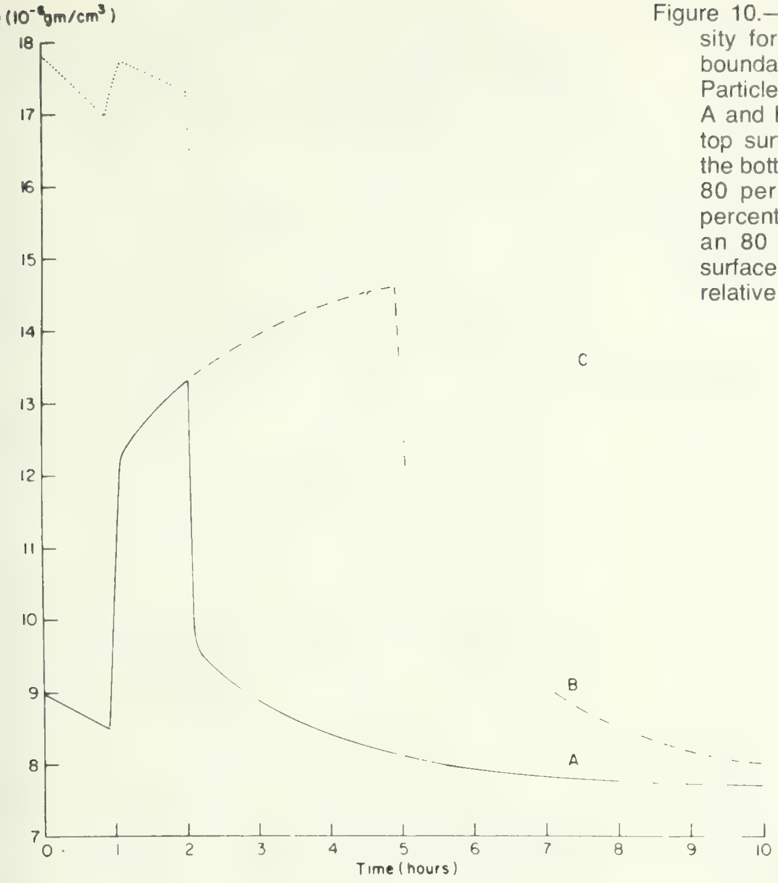


Figure 10.—Time response of integral void vapor density for homogeneous litter layers under varying boundary conditions. Bulk density is 0.03 gm cm^{-3}. Particle timelag is 3,600 sec. Thickness is 8 cm. Lines A and B had a 20 percent relative humidity on the top surface and a 40 percent relative humidity on the bottom surface. The top surface was changed to 80 percent relative humidity. Line C had a 20 percent relative humidity on the top surface and an 80 percent relative humidity on the bottom surface. The top surface was changed to 40 percent relative humidity.

ude of the structure timelag. Examination of the forcng and response functions suggests a magnitude imilar to that reported by Johnson (1968).

Data used by Johnson (1968) and Van Wagner 1970) come from observations taken once a day. Thus, he reported responses were artificially forced to long imelags since the minimum resolvable timelag cannot e less than 1 day. Data collected at high sample rates[6] how high response rates and short timelags similar o those predicted by the theoretical solutions. Thus, liscrepancies between the theoretical solution and imelag values previously reported are due to artificial iltering created through sampling procedures.

Comparisons of the theoretical prediction to bservation were made with Nelson's (1969) experinental results in sawdust layers. The theory predicted timelag of 360 minutes, while Nelson observed timeags that ranged from 390 to 420 minutes for low noisture timelags. Measured timelags of ponderosa

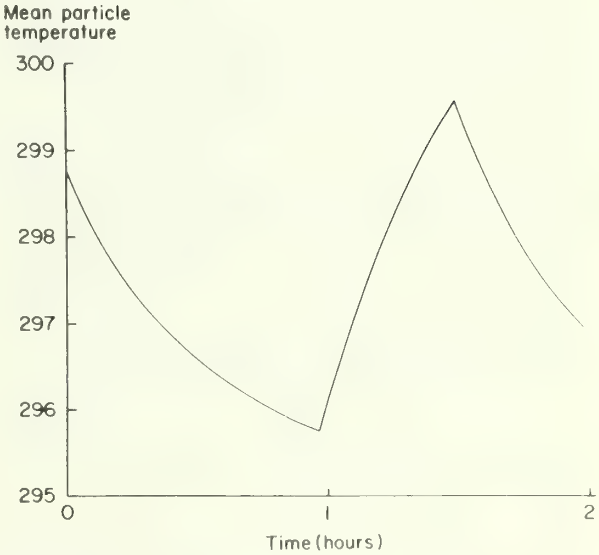


Figure 11.—Time response of integral particle temperature for homogeneous litter layer under varying boundary conditions. Bulk density is 0.03 gm cm^{-3}. Particle timelag is 6 sec. Layer is 8 cm thick.

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[6] *McLeod, Bruce. December 7, 1973, Microwaves, a new ool for forest and watershed management. 15 p. (Unpublished eport, Mont. State Univ., Bozeman.)*

pine needles in loosely packed beds[7] were close to those predicted by the theoretical solutions.

Conclusions

The theoretical model developed in this paper is a generalization of previously derived theoretical solutions. The improvement over traditional solutions was obtained by following the physical processes more closely. Three main quantitative results were obtained from the theoretical predictions.

The first was the prediction of timelags from physical properties of particles and from horizon structure. These thermal and vapor timelags provide basic coefficients for analytical predictions of heat and vapor exchanges. Thermal and vapor timelags cannot be calculated as the particle timelags go to zero. Nonsorbing porous media flow is depicted by the simple analytical solution and similarity is not preserved. While this limitation indicates that the solutions are not completely generalized, calculations over the range of properties in organic soils are valid.

The second primary result was two pairs of prediction equations. The first pair apply to heat and vapor changes with constant boundary conditions and initially homogeneous profiles. These equations depict the behavior of the horizons in the laboratory. The second pair of equations for heat and vapor change prediction relax the requirement of initially homogeneous profiles and constant boundary conditions. This pair of equations depicts the processes under natural or field conditions of temperature and moisture profiles.

These solutions for field conditions permit a variable set of boundary conditions. The equation requires surface temperature and the vapor density at the surface. Because the boundary conditions are held constant over a small integration interval, but can vary between finite intervals, the boundary conditions are actually finite difference approximations to the continuous change. The homogeneity coefficient in these field-applicable equations reflects the departure of the initial state from homogeneous temperature and moisture profiles. If most of the changes in temperature and moisture are determined by surface boundary conditions, then the homogeneity coefficient will be less than one. A coefficient of less than one then indicates a deep, slowly changing reservoir. A coefficient of one applies only in the laboratory. Coefficients greater than one indicate quiescent surface conditions, with most of the change taking place in the deeper horizons.

The third quantitative result was the recalculation of the bulk diffusivities for nonsorbing particles. These bulk diffusivities are the same as those traditionally determined in the laboratory, and are based on the assumption of instantaneous response of the particles.

The model requires horizon thickness, porosities, and particle timelags to make the predictions. The particle timelags must be determined in the laboratory. Neither particle timelags nor densities vary much between samples. Bulk densities of each horizon also vary within a narrow range, so the porosity can be calculated from the particle and bulk densities. Horizon depth varies widely even in small plots of constant basal area, so that there is a large potential uncertainty in extrapolation of an individual calculation to different sites. The only other data requirements of the model are the boundary conditions. These data are the temperature and atmospheric moisture content at the upper surface.

The model can be applied to forestry problems such as fire danger by specifying the physical properties of thickness, particle timelag, and porosity. With these data the vapor and thermal timelags can be calculated. The field prediction equations are then solved sequentially for each horizon. The external boundary conditions of surface temperature and vapor density apply to the surface horizon. The temperature and vapor density boundary conditions for internal horizons are specified by the vapor density and temperature of the adjacent higher horizon. The lowest horizon must be selected sufficiently deep—such as below the depth of diurnal fluctuation for prediction extending a few days or below the depth of annual fluctuation for seasonal calculation—to eliminate the lower boundary condition. Since the moisture content timelag and vapor density timelag are nearly identical, the moisture content profiles can be calculated directly from the equilibrium moisture isotherms. These theoretical solutions do not contain liquid water processes. Addition of liquid water can be considered through minor modification of classic infiltration theory and therefore complete the model of practical application.

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[7] *Anderson, Hal. E., Robert W. Mutch, and Robert D. Schuette. 1975. Timelag and equilibrium moisture content of ponderosa pine needles. 20 p. (Unpublished manuscript, U.S. For. Serv., Missoula, Mont.)*

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Appendix—List of Symbols

Symbol	Definition	Units
C_p	Specific heat of air constant pressure	cal gm^{-1} $°K^{-1}$
e	Vapor pressure in air	dynes cm^{-2}
e_s	Saturation vapor pressure	dynes cm^{-2}
F_M	Similarity number for moisture transfer in litter and duff	dimensionless
$\hat{F}_M$	Similarity number for moisture transfer in nonsorbing porous media	dimensionless
F_T	Similarity number for heat transfer in litter and duff	dimensionless
$\hat{F}_T$	Similarity number for heat transfer in nonsorbing porous media	dimensionless
H	Thickness of a homogeneous horizon	cm
h	Relative humidity	percent
k_B,k	Thermal diffusivity in voids	cm^2 sec^{-1}
k_o	Thermal diffusivity in free air	cm^2 sec
$\bar{k}$	Effective thermal diffusivity in litter or duff	cm^2 sec^{-1}
M_a	Mass of air in litter or duff volume	gm
M_F	Mass of litter particles in litter or duff volume	gm
m	Moisture content of litter or duff (mass of contained water to ovendry mass of particle)	percent
m_e	Equilibrium moisture content	percent
m_i	Initial moisture content	percent
q	Arbitrary scalar variable	dimensionless
q_e	Equilibrium value of arbitrary scalar	dimensionless
q_o	Initial value of arbitrary scalar	dimensionless
R	Gas constant for water vapor	cal gm^{-1} $°K^{-1}$
s	Source or sink of heat in litter or duff	cal
T	Temperature in litter or duff	deg K
t	Time coordinate	sec

Appendix—List of Symbols (Continued)

Symbol	Definition	Units
V_B	Volume of litter or duff	cm^3
V_F	Volume of particles in litter or duff	cm^3
V_v	Volume of voids in litter or duff	cm^3
z	Vertical space coordinate	cm
β	Packing ratio (1 − porosity)	dimensionless
Δm	Potential change of particle moisture content	percent
ΔT	Potential change of particle temperature	deg K
δH_a	Change of heat in litter or duff voids	cal
δH_F	Change of heat in litter or duff particles	cal
δm	Change of moisture content in particles	percent
$\delta T_F, \delta T$	Change of temperature in particles	deg K
δt	Finite time step	sec
ζ_M	Homogeneity coefficient for moisture transfer	dimensionless
ζ_T	Homogeneity coefficient for heat transfer	dimensionless
ρ_a	Density of air	$gm\ cm^{-3}$
ρ_B	Bulk density of litter or duff	$gm\ cm^{-3}$
ρ_f	Density of litter or duff particles	$gm\ cm^{-3}$
ρ_v	Water vapor density in voids	$gm\ cm^{-3}$
$\rho_{v'}$	Water vapor density equivalent of moisture in particles	$gm\ cm^{-3}$
τ_{BM}	Moisture timelag of homogeneous horizon of litter or duff	sec
τ_{BT}	Thermal timelag of homogeneous horizon of litter or duff	sec
τ_{PM}	Moisture timelag of litter or duff particle	sec
τ_{PT}	Thermal timelag of litter or duff particle	sec
ν, ν_B	Moisture diffusivity in voids	$cm^2\ sec^{-1}$
ν_0	Moisture diffusivity in free air	$cm^2\ sec^{-1}$

Appendix—List of Symbols (Continued)

Symbol	Definition	Units
$\hat{\nu}$	Effective moisture diffusivity in litter or duff	$cm^2\ sec^{-1}$
ϕ	Porosity of litter or duff (Volume of voids/volume of horizon)	dimensionless
χ	Source or sink of moisture in litter or duff	percent

Fosberg, Michael A.
1975. Heat and water vapor flux in conifer forest litter and duff: a theoretical model. USDA For. Serv. Res. Pap. RM-152, 23p. Fort Collins, Colo. 80521.

The model was developed from numerical and analytical solutions of the diffusion forms of the mass continuity equation and the first law of thermodynamics. Analytical solutions provided a functional framework to evaluate nonlinear interactions obtained in the numerical solutions. Dimensional analysis was used to define the relationships between the soil properties used in the model.

Keywords: Soil physics, forest fires, forest fuels.

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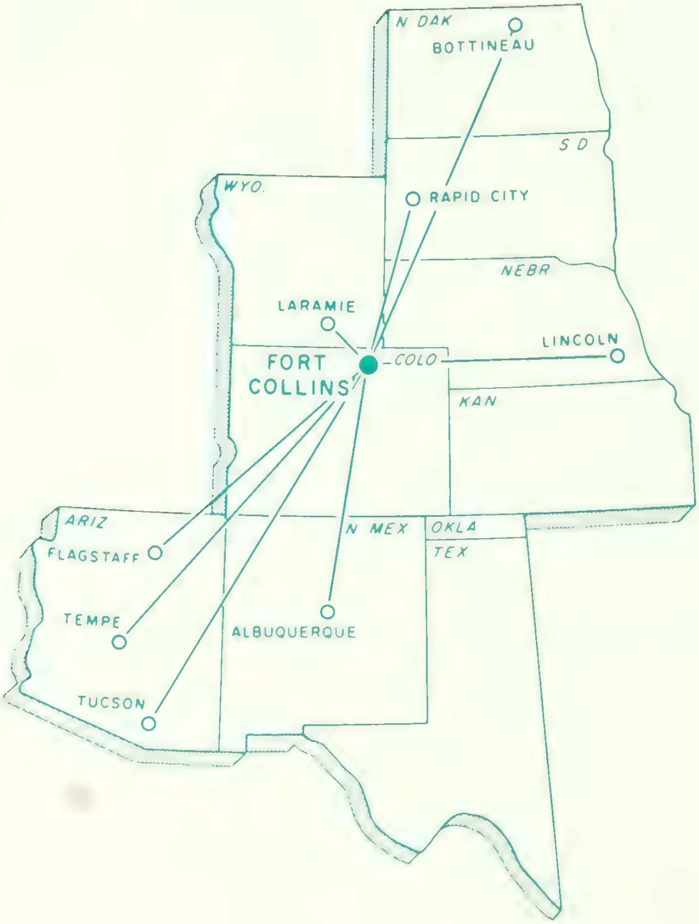
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hytotoxic Grass Residues educe Germination and nitial Root Growth of onderosa Pine

. J. Rietveld

USDA Forest Service
Research Paper RM-153

September 1975

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

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Abstract

Rietveld, W. J.
1975. Phytotoxic grass residues reduce germination and initial root growth of ponderosa pine. USDA For. Serv. Res. Pap. RM-153, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Extracts of green foliage of Arizona fescue and mountain muhly significantly reduced germination of ponderosa pine seeds, and retarded speed of elongation and mean radicle length. Three possible routes of release of the inhibitor were investigated: (1) leaching from live foliage, (2) root exudation, and (3) overwinter leaching from dead residues. The principal route remains uncertain. The ecological implications of the inhibitory substance are discussed.

Keywords: *Muhlenbergia montana* (Nutt.) Hitchc., *Festuca arizonica* Vasey, *Pinus ponderosa* Laws., allelopathy, phytotoxic substances, plant competition, chemical ecology.

COVER: An example of the ponderosa pine-bunchgrass community of northern Arizona. Clearcut logging in the early 1920's allowed the subclimax bunchgrasses, *Festuca arizonica* and *Muhlenbergia montana,* to capture and dominate the site in nearly pure stands for over 50 years.

USDA Forest Service
Research Paper RM-153

September 1975

Phytotoxic Grass Residues Reduce Germination and Initial Root Growth of Ponderosa Pine

W. J. Rietveld, Plant Physiologist
Rocky Mountain Forest and Range Experiment Station[1]

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[1] *Central headquarters is maintained at Fort Collins in cooperation with Colorado State University; research reported here was conducted at the Station's Research Work Unit at Flagstaff, in cooperation with Northern Arizona University.*

CONTENTS

Page

Introduction 1

Chemical Ecology: Chemical Interactions among Species 1

Experimental Studies and Results 2

- Germination of Seeds and Growth of Seedlings in Aqueous Extracts of Grass Residues 2
  - Materials and Methods 2
  - Results and Discussion 3
- Growth of Various Species Associations in Sand Culture 6
  - Materials and Methods 6
  - Results and Discussion 8
- Seed Germination in Leachates from Grass Residues 10
  - Materials and Methods 10
  - Results and Discussion 10
- Overwintering of Pine Seeds under Various Plant Residues 10
  - Materials and Methods 11
  - Results and Discussion 11

Discussion of Ecological Significance 12

Conclusions 13

Literature Cited 14

Phytotoxic Grass Residues Reduce Germination and Initial Root Growth of Ponderosa Pine

W. J. Rietveld

INTRODUCTION

The widespread pine-bunchgrass community of northern Arizona consists of ponderosa pine (*Pinus ponderosa*), Arizona fescue (*Festuca arizonica*), and mountain muhly (*Muhlenbergia montana*) as principal species. Typically, the ponderosa pine forest supports a grass understory of varying density which extends through parklike landscapes. Best development of the community occurs on better soils where the pine overstory is less than 20 square feet basal area per acre, with frequent larger openings.

In parklike stands and openings created by fire or logging, the bunchgrasses promptly capture the site, and develop into dense, exclusive communities seemingly impenetrable by other species. Numerous examples are found near Flagstaff where the ponderosa pine climax has not returned in 50 to 100 years after fire or timber harvesting (Schubert 1974). Seeds from surrounding trees repeatedly fall in these openings, but few seedlings emerge. Pine seedlings transplanted directly into the grasses typically fail to survive or grow poorly. Even where dense grass cover is mechanically removed, survival and growth of planted trees may be depressed.

In addition to competition for available water, nutrients, and growing space, chemical interactions (allelopathy) may play an important role in plant competition. Jameson (1961, 1968) tested for the presence of growth inhibitors in Arizona fescue and other northern Arizona native species, and found that an aqueous extract of fescue foliage inhibited radicle elongation of squirreltail (*Sitanion hystrix*), blue grama (*Bouteloua gracilis*), and ponderosa pine. Elongation of pine radicles in fescue extract was only 40 percent of that in water. In a small pilot test, ponderosa pine seed overwintered under Arizona fescue litter were found to have reduced germination the following summer (USDA-FS 1957). Seeds subjected to fescue leachings had only 63 percent germination, compared to 90 percent for uncovered seed.

This Paper reports research to determine (1) if various grass residues contain substances phytotoxic to ponderosa pine, and (2) their route of release.

CHEMICAL ECOLOGY: CHEMICAL INTERACTIONS AMONG SPECIES

Many interactions between plants can be attributed to such specific factors as competition for light, water, nutrients, and growing space; susceptibility or immunity to insects and diseases; and the differential effects of other environmental stresses. However, it has become increasingly apparent that there are some interactions involving chemical substances released from one plant which negatively influence another plant. The study of these interactions is the subject of the new and rapidly expanding field of chemical ecology (Sondheimer and Simeone 1970). Many terms have been applied to the toxic chemicals and chemical effects of one species on another, but the term allelopathy (meaning mutual harm) is most commonly used. Whittaker (1970, p. 44) defined allelopathic substances as "chemicals that are released from higher plants (directly or by way of decay processes) that inhibit the germination, growth, or occurrence of other plants."

Evidence regarding the occurrence and ecological roles of allelopathy is voluminous, and has been reviewed repeatedly and comprehensively.[2] Allelopathic effects have been reported for agricultural and wild species of most growth forms and habitats.

The routes by which allelopathic substances reach the soil from aboveground plants include adsorption of volatile materials on soil particles, rain washing of soluble materials from living plant surfaces, leaching of materials from plant litter (or seedcoats) on the soil surface, and release of toxic compounds during microbial decomposition of litter. Routes of release within the soil include root exudation, leaching from living and dead roots, and decomposition of dead roots and incorporated residues (Whittaker 1971).

Liberation of phytotoxic substances from grasses and grasslike plants capable of inhibiting germination and/or growth of another species appears to be a widespread phenomenon.[3] The nature of the allelopathics, route of release, and mode of action in most cases is species specific, that is, the allelopathic mechanism has evolved to fulfill a particular ecological role. Barley, for example, inhibits all other plants around it. *Hordeum spontaneum* grows in the wild state in almost pure stands (Went 1970), and the cultivated species *Hordeum sativum* successfully excludes weeds from fields by excretion of inhibitors from its roots (Overland 1966). Quackgrass (*Agropyron repens*), a widespread weed, inhibits growth of cultivated plants by release of inhibitors from decaying roots which interfere with mineral nutrition (Grümmer 1961). The tillage practice of stubble mulching, which places residues of oat, wheat, corn, or sorghum on the soil surface, has resulted in reduced growth of subsequent crops. Liberation of phenolic acids to the soil during microbial decomposition of the residues was found to be responsible. Bacterial metabolism of these compounds in the soil resulted in the formation of other toxic substances (Guenzi and McCalla 1966).

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[2] *Published reviews include those by Bonner (1950), Börner (1960), Evenari (1949), Garb (1961), McCalla and Haskins (1964), Muller (1966), National Academy of Sciences (1971), Rice (1974), Sondheimer and Simeone (1970), Whittaker and Feeny (1971), and Woods (1960).*

Allelopathic effects also may be a significant influence in the sequence and timing of succession of plant communities. A dominant species may, by allelopathic suppression, speed its invasion of a community and delay its replacement by other species (Whittaker 1970, 1971). Studies on old-field succession in Oklahoma (Rice 1971, 1972; Wilson and Rice 1968) showed that sunflower (*Helianthus annuus*), one of the dominants of the first stage of succession, produces substances inhibitory to most other species of the stage. Threeawn (*Aristida oligantha*), an annual grass, quickly invades because it is tolerant of the toxic substances as well as low soil nitrogen levels. Threeawn maintains dominance for several years by allelopathic suppression of nitrogen-fixing bacteria and blue-green algae, thereby keeping soil nitrogen at levels too low to support species from later stages of succession. Eventually, broomsedge (*Andropogon virginicus*), which is also tolerant of low-fertility soils, replaces threeawn by means of chemical inhibition and competition, and for many years delays replacement by its successor, little bluestem (*Andropogon scoparius*).

Of 20 species involved in the old-field successions, 16 species had some and 10 considerable inhibitory activity against nitrogen-fixing and nitrifying bacteria (Abdul-Wahab and Rice 1967; Rice 1964, 1965; Rice and Parenti 1967).

There is considerable potential for chronic and indirect allelopathic effects. Relative allelopathic effects vary with the levels of phytotoxic substances, the kind of soil and other environmental conditions, and the sensitivity of different plant species. It is reasonable to postulate that the observed cases of allelopathy stand out from a background of more widespread, less conspicuous effects on plant growth and plant distribution. The combined influence of allelopathy and competition could explain why certain species quickly capture a site following disturbance, and persist for so long in almost pure stands before the climax vegetation is ultimately restored.

EXPERIMENTAL STUDIES AND RESULTS

Germination of Seeds and Growth of Seedlings in Aqueous Extracts of Grass Residues

A laboratory experiment was conducted to determine the phytotoxic effects of various residues of fescue and muhly on seed germination and primary root elongation of ponderosa pine.

Materials and Methods

Samples of fresh green foliage (including seedstalks), new litter (standing dead grass litter), old litter (matted dead litter accumulated in the center of the clump), and roots (live roots clipped from growing grass plants) of fescue and muhly were collected in mid-September on the Fort Valley Experimental Forest near Flagstaff, Arizona. Excess soil was shaken from the grass roots, but they were left unwashed to avoid losing any excreted phytotoxins. The residues were air-dried for 26 days, then ground in a mill to pass a 20-mesh screen. Powdered residues were refrigerated in sealed metal cans until use.

Each extract was prepared by homogenizing 20 g of powdered residue with 200 ml of sterile distilled water in a blender at low speed for 15 minutes. The extracts were centrifuged (5,600 rpm for 10 minutes) and filtered, using suction to remove suspended matter. The control "extract" consisted of sterile distilled water homogenized for 15 minutes. The pH and osmotic potential (by cryoscopy, Harris and Gortner 1914) of the freshly prepared extracts were measured.

Extracts used in the germination tests were not sterilized since heat might affect stability of inhibitory substances in the extracts, and the chemical sterilants sodium benzoate and sodium hypochlorite were found to inhibit pine seed germination. To reduce fungal contamination, seeds were surface-sterilized by soaking in 30 percent hydrogen peroxide for 15 minutes and rinsed with sterile distilled water, and all glassware and glass filter paper were sterilized by autoclaving. The interior of the growth chamber was washed with sterilizing chemicals. Five ml of unsterilized extract was added to each petri dish only once; sterile distilled water was added when additional water was needed. Control dishes were wetted with 5 ml of sterile distilled water.

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[3] *The occurrence of toxic substances has been reported in western wheatgrass (Jameson 1961), squirreltail (Jameson 1961, 1968), cheatgrass (Jameson 1961), Johnsongrass (Hoveland 1964), Bermudagrass (Hoveland 1964), blue grama (Jameson 1968), Sudangrass (Patrick, Toussoun, and Snyder 1963), quackgrass (Grümmer 1961), timothy (Patrick and Koch 1958), rye (Holm 1969, Patrick and Koch 1958; Patrick, Toussoun, and Snyder 1963), false flax (Grümmer 1960), brome (Myers and Anderson 1942), as well as oat, wheat, and barley (Guenzi, McCalla, and Norstadt 1967; Holm 1969; Patrick, Toussoun, and Snyder 1963).*

The experiment was conducted in a controlled environment chamber held at a constant temperature of 75°F and a photoperiod of 16 hours of combined fluorescent and incandescent lighting daily. The incandescent lights were turned off 15 minutes after the fluorescent lights to expose the seeds to light in both the red and far-red regions at the end of each day, as in the natural condition. Relative humidity was maintained above 80 percent. The arrangement of petri dishes, four per treatment combination, in the growth chamber was completely randomized; locations were shifted daily to distribute the effects of microclimatic variation.

Seeds were considered germinated when the radicle length equaled the length of the seed. The number of germinated seeds was recorded daily for 25 days. Radicle length (in millimeters) from the seedcoat or cotyledons to radicle tip, of the first 10 seeds to germinate in each petri dish, was measured daily until the seedlings began to decline due to exhaustion of the endosperm and growth factors contained in the extracts. Fungal contamination was not serious until the last days of the experiment, but 90 percent of the germination had occurred by that time.

Percentage germination, speed of germination (Maguire 1962), time for 50 percent germination, speed of elongation (adapted from Maguire 1962), and mean radicle length before decline were calculated and tested for significant differences by factorial analysis of variance. Speed of germination and elongation take both the promptness and completeness of the respective processes into account.

Results and Discussion

Extracts prepared from live foliage of fescue (FF) and muhly (MF) by far produced the most dominant effects (fig. 1). With few exceptions, FF and MF extracts significantly ($\alpha = 0.01$) reduced percentage germination and speed of germination, increased time for 50 percent germination, and reduced speed of elongation and mean radicle length. FNL similarly inhibited seed germination, speed of elongation, and mean radicle length, but to a lesser degree than extracts from live foliage. The magnitude of these effects is apparent in figure 1 in which speed of germination of seeds and speed of elongation of radicles in the extracts are expressed as percentages of the control values. A few inconsistent, less significant effects appear in the data: MR extract inhibited mean radicle length and FOL increased percentage germination and speed of germination. These results could be reverse responses to low concentration of a growth substance or due to secondary metabolites in the extracts. However, the variance for mean radicle length was high, and these results may simply be chance events.

Retarded pine germinants tended to have a stocky appearance with a shortened, stubby radicle and short hypocotyl. Other symptoms were an enlarged root collar and dark brown sheath covering both the root collar and radicle tip. In the most toxic extracts the radicle tip eventually died.

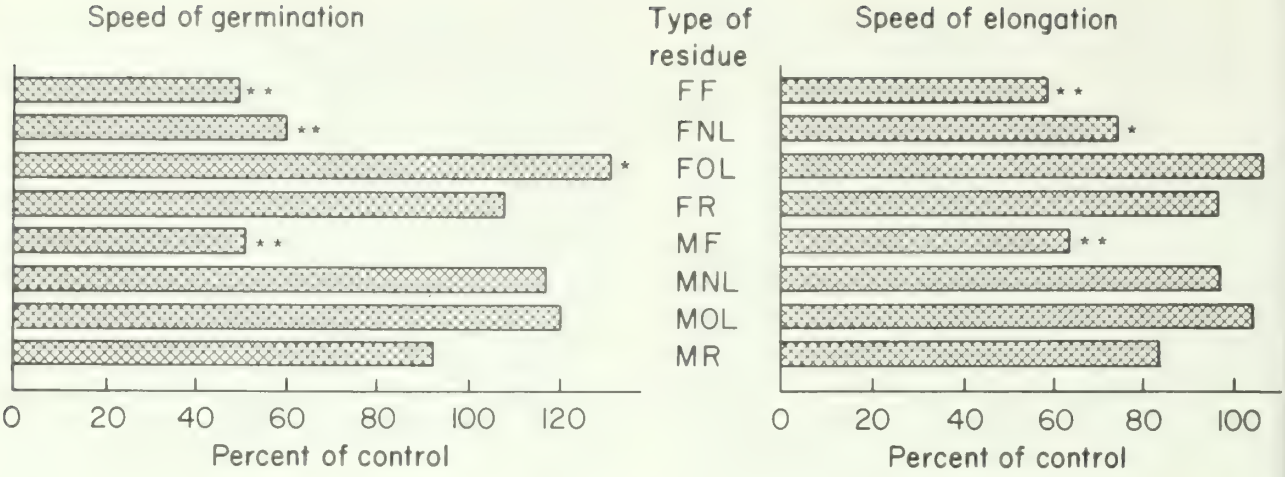
The pH and osmotic potential of aqueous extracts of grass residues were as follows:

Source of extract	**pH**	**Osmotic potential** (*atm*)
FF	5.70	-2.60
FNL	4.58	-0.50
FOL	5.80	-0.30
FR	6.14	-0.60
MF	5.67	-1.60
MNL	4.87	-0.60
MOL	5.59	-0.30
MR	5.80	-0.60
Control	5.49	0.00

The pH of the control "extract" was slightly acidic due to the incorporation of carbon dioxide by the blender. Although no tests were run, pH values are not considered to be low enough to significantly affect seed germination or initial growth. Moreover, the pH values of the extracts that induced the strongest responses (FF, FNL, MF) are similar to the control.

Extract osmotic potential decreased with increasing age and decomposition of residues. Extracts that significantly inhibited germination and initial development also had the lowest osmotic potentials, especially FF and MF. Larson and Schubert (1969a) reported that moderately low osmotic potentials (down to -3 bars) benefit germination of ponderosa pine seeds, but the reason for this response, as well as the effects on speed of germination, and speed of elongation of pine, are unknown.

The separate effects of extract osmotic potential were tested in a followup experiment in which pine seeds were germinated in solutions of polyethylene glycol (PEG, molecular weight 20,000) with osmotic potentials of -1, -2, -4, and -8 atmospheres. Percentage germination, speed of germination, and



Mean germination (Percent)	Mean speed of germination (No./day)	Mean time for 50 percent germination (Days)		Mean speed of elongation (mm/day)	Mean radicle length (mm)
27.5**	3.5**	7.6*	FF---Fescue foliage	3.2**	26.0**
31.9*	4.2**	7.4	FNL--Fescue new litter	3.7*	27.1**
66.0*	9.2*	6.4	FOL--Fescue old litter	5.3	36.6
56.3	7.6	6.8	FR---Fescue roots	4.8	33.4
29.2**	3.6**	8.5**	MF---Muhly foliage	3.2**	24.1**
62.3	8.2	7.1	MNL--Muhly new litter	4.9	35.3
62.2	8.5	6.9	MOL--Muhly old litter	5.2	38.4
51.4	6.5	7.3	MR---Muhly roots	4.2	30.8*
49.3	7.0	6.1	Control	5.0	37.7
0.0198	4.1418	1.0805	Variance (s^2)	1.0805	38.0467
14.0	2.0	1.4	Least significant difference (5%)	1.0	6.2
18.7	2.7	1.8	Least significant difference (1%	1.4	8.2

*Differs significantly from control at 5% level.
**Differs significantly from control at 1% level.

Figure 1.—Germination and growth responses of ponderosa pine to extracts prepared from grass residues.

speed of elongation were measured under the same experimental conditions described previously. The PEG solutions and distilled water control were changed daily to minimize the increase in concentration of the solutions by seed imbibition of water. Percentage germination of pine seeds (fig. 2A) is enhanced by low levels of osmotic potential, beyond which germination drops off gradually. This pattern is in general agreement with the results of Larson and Schubert (1969a). Speed of germination of pine seeds (fig. 2B) followed a trend similar to percentage germination within the range tested, but to a lesser degree. Speed of elongation of pine radicles (fig. 2C was found to be quite sensitive to osmotic potentia at all potentials tested below -1 atmosphere. Overall in the range 0 to -3 atmospheres, which includes the osmotic potential of the extracts, osmotic potentia should not interfere significantly with percentage o speed of germination of pine seeds. Speed o elongation of pine is sensitive to the osmotic potentia of the wetting solution.

Thus, extract osmotic potential was a principa confounding factor which inconsistently accounted for part of the observed responses to the extracts.

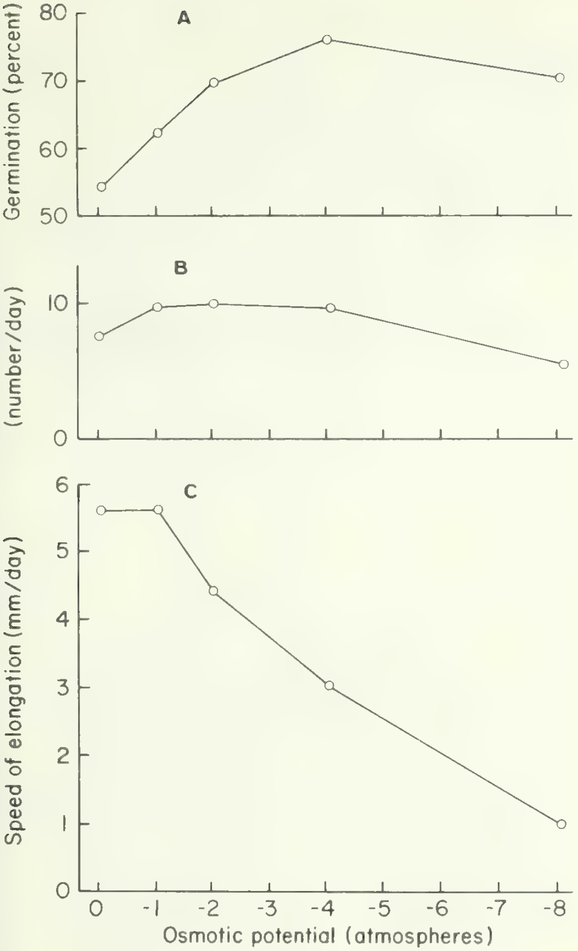


Figure 2.—Effects of different osmotic potentials imposed by solutions of polyethylene glycol (PEG) on: **A**, percentage germination; **B**, speed of germination; and **C**, speed of elongation of ponderosa pine.

When extract osmotic potential is taken into account, the inhibitory effects of FF, FNL, and MF extracts on percentage germination and speed of germination (figs. 3A and 3B) would be greater, rather than lesser, compared to the control values. Speed of elongation of pine (fig. 3C) radicles would likely not be significantly different from the respective controls when the separate effects of extract osmotic potential are taken into account. If the controls consisted of PEG solutions with osmotic potentials equivalent to the extracts, the actual depression of germination of pine seeds by FF extract, for example, would be 61.4 percent (fig. 3A) of the control compared to 44.2 percent calculated from the tabulation in figure 1. Speed of germination of pine seeds was depressed 50 percent of the control value in figure 1, and 64.3 percent if extract osmotic potential is taken into account (fig. 3B). However,

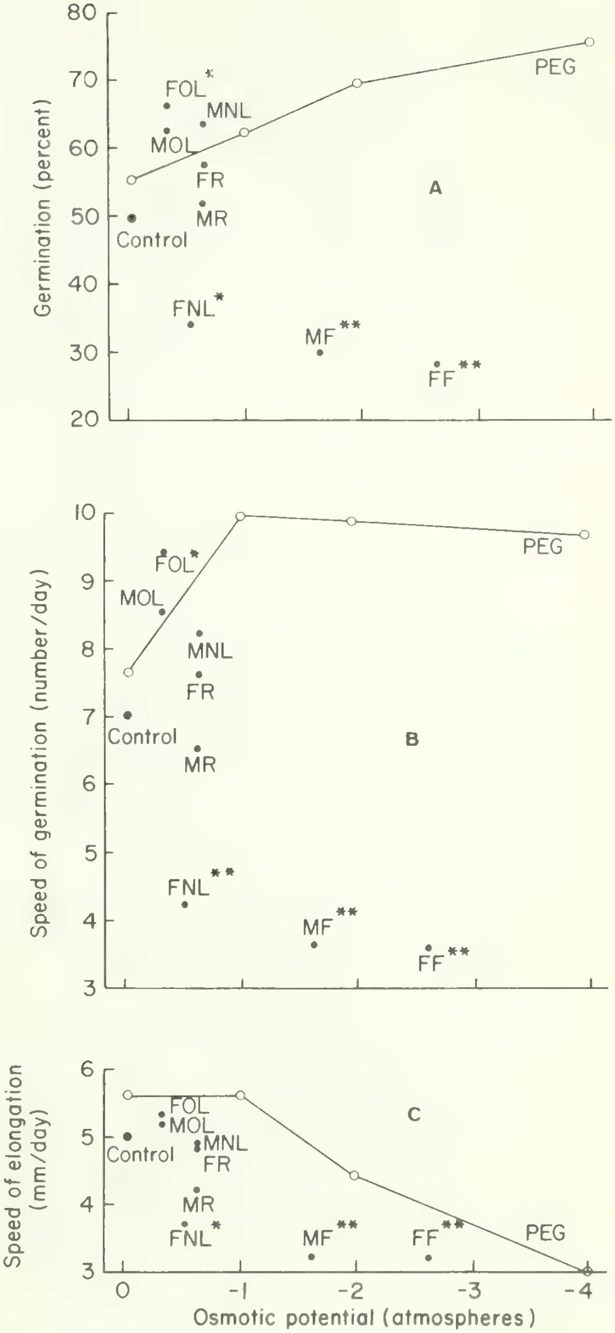


Figure 3.—Comparisons of: **A**, percentage germination; **B**, speed of germination; and **C**, speed of elongation of ponderosa pine in polyethylene glycol (PEG) solutions and grass residue extracts of different osmotic potentials. One asterisk indicates the difference between the extract and control values is significant at the 0.05 probability level; two asterisks indicate significance at the 0.01 probability level.

for speed of elongation of pine radicles, the actual depression is 16.5 percent (fig. 3C) compared to 36 percent calculated from the tabulation in figure 1. Thus, elongation of pine radicles appears to be much more sensitive to the osmotic potential of the wetting solution than is seed germination.

The extract experiment also revealed that pine seeds germinate much better under conditions of limited water than under wet conditions. Apparently the improved aeration and small negative water potential afforded by minimum wetting stimulated germination. This is illustrated also by the ability of ponderosa pine seeds to withstand air-drying during germination (Larson and Davault 1975).

The low percentage germination of 49.3 for the pine control treatment (fig. 1) is attributed to overwetting (5 ml water per 9 cm petri dish). Also, fungal contamination may have interfered. To test these possibilities, a small experiment was performed to test the effects of sterilized FF and MF extracts, 3 ml per petri dish, on germination of surface-sterilized pine seeds. All glassware was similarly sterilized by autoclaving. The test was run in a small germinator without light at 75°F with high humidity. Germination in the control treatment was much higher, 84.8 percent, than in the original experiment (fig. 4), but the differences in germination between the extracts and the control persisted:

Source of extract	**Germination** *(Percent)*	*(No./day)*
FF	62.3	11.9
MF	60.8	11.8
Control	84.8	17.9

As a consequence of higher percentage germination, speed of germination was correspondingly higher than in the original experiment. However, the treatment differences are consistent.

Another followup experiment was run to determine the effects of extract added after germination. Fescue foliage extract, 1 or 2 ml per 7 cm petri dish, was added to pine germinants with radicles ½ or 1 inch long. Response was evaluated during a 3-day incubation period. The results were similar regardless of initial radicle length: 2 ml of extract per dish retarded radicle elongation by 30 percent. Thus, it appears that the inhibitory substance retards both germination and initial growth processes, rather than the latter being a consequence of the effects upon germination.

Growth of Various Species Associations in Sand Culture

The sand culture experiment was one of three experiments conducted to investigate possible routes of release of the inhibitory substance. Paired combinations of pine, fescue, and muhly were grown in intimate contact to (1) determine if inhibitory substances are excreted by grass roots, and (2) measure their relative toxicity to an associated pine or grass plant.

Materials and Methods

Pine, fescue, and muhly seeds were germinated in petri dishes. Pairs of plants in all possible combinations of the three species were then planted in 4½-inch-diameter by 10-inch deep metal pots. The pots were filled with an equal weight of number 60 silica sand and a 1-inch layer of Perlite on the surface to reduce evaporation. Group A consisted of 36 pots of plants with simultaneous planting times; Group B contained 36 pots of plants with age differing by 3 months.

The experiment was conducted in a controlled environment chamber programed for two periods of plant growth separated by a 10-week cool period. The warm environment consisted of a thermoperiod of 75°F during the day and 60°F during the night, and photoperiod of 16 hours of combined fluorescent and incandescent lighting. The transition period of temperature changes coincided with light changes, and a 15-minute period of twilight was provided at day end as described previously. After 4 months under the warm environment, the growth chamber was set for a cool environment of 10 weeks' duration, consisting of a thermoperiod of 50°F during the day (8 hours) and 35°F at night. Following the cool period, the warm environment was resumed for an additional 3 months.

A watering system based on the relationship between matric potential and water content was developed which regulated soil moisture potential within the range of -0.3 atmosphere (field capacity) and -3.0 atmospheres by a corresponding range in pot weight. The plants were watered with one-half strength Hoagland solution at 2- to 4-day intervals during the entire experiment to maintain water and nutrients at adequate levels. Leaching of the pots at monthly intervals was necessary to remove accumulated salts. Each pot was leached with 2,000 ml of water. Since phytotoxins excreted from roots could be lost in the water leached from the pots, the first 250 ml of leachate from each pot in Group A was collected and tested for toxicity to yellow sweetclover (*Melilotus officinalis*) seed germination.[4] A 25 ml

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[4] *Germination and initial growth of yellow sweetclover were found to be extremely sensitive to the phytotoxins produced by Arizona fescue and mountain muhly, and therefore provided a quick bioassay for the presence of the inhibitor(s).*

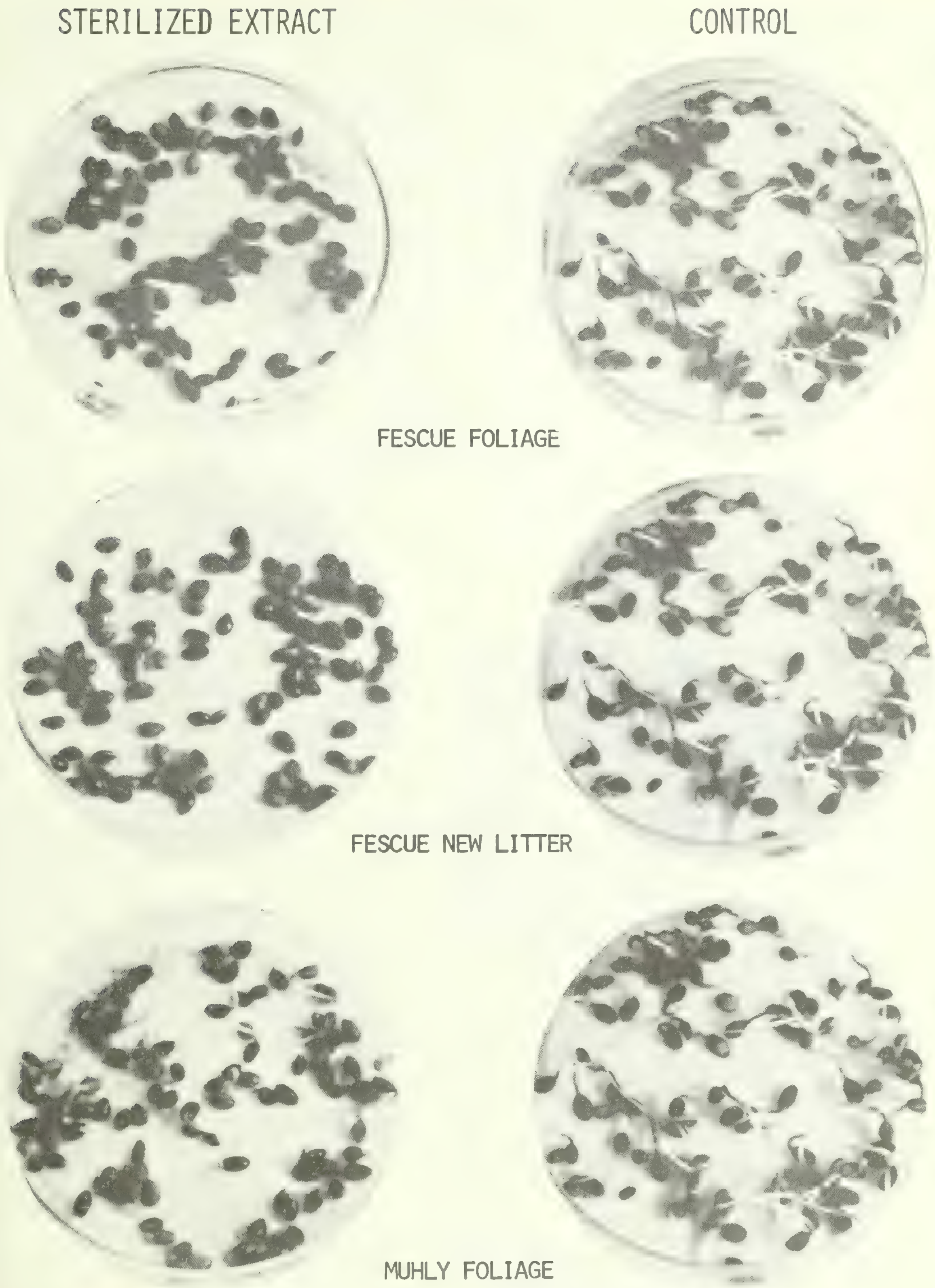

Figure 4.—Germination of surface-sterilized pine seeds in sterilized extracts compared with the control.

aliquot of the leachate from each pot was evaporated to dryness, rewetted with 3 ml of distilled water and added to 100 clover seeds in a petri dish; distilled water only was used as a control. The osmotic potential of the leachates was not determined.

Foliage height (distance from cotyledons to shoot tip) of pine, and total height and basal diameter of the two grasses, were measured monthly for the 9-month duration of the experiment. At the end of the experiment, dry weight of the top and roots of individual plants was determined. These data and calculated top/root weight ratios and plant volumes (grasses) were analyzed for significant differences by analysis of variance.

Results and Discussion

Though the experiment was designed to test for toxic root excretions in the absence of competition for light, water, and nutrients, strong plant competition developed as early as 3 months into the experiment and intensified as the experiment progressed. Because of competition, it was very difficult to establish the second species in the later planting, especially where large fescue and muhly plants were present. Toward the end of the experiment, the pots were distinctly crowded by large grass plants (fig. 5), and most pine seedlings planted 3 months after the grass were suppressed or dead. This awesome demonstration of the competitive power of fescue and muhly is in accord with the results of Larson and Schubert (1969b), especially with regard to planting pines in an established grass stand. Seedlings that died were assigned a value of zero for their corresponding data.

The data presented in table 1 for Group A show mainly the effects of plant competition, or lack of it, on various growth parameters. Fescue plants made superior growth in terms of top and root dry weight and top volume when associated with pine compared to another fescue or muhly plant. The lack of competition from the associated pine is undoubtedly

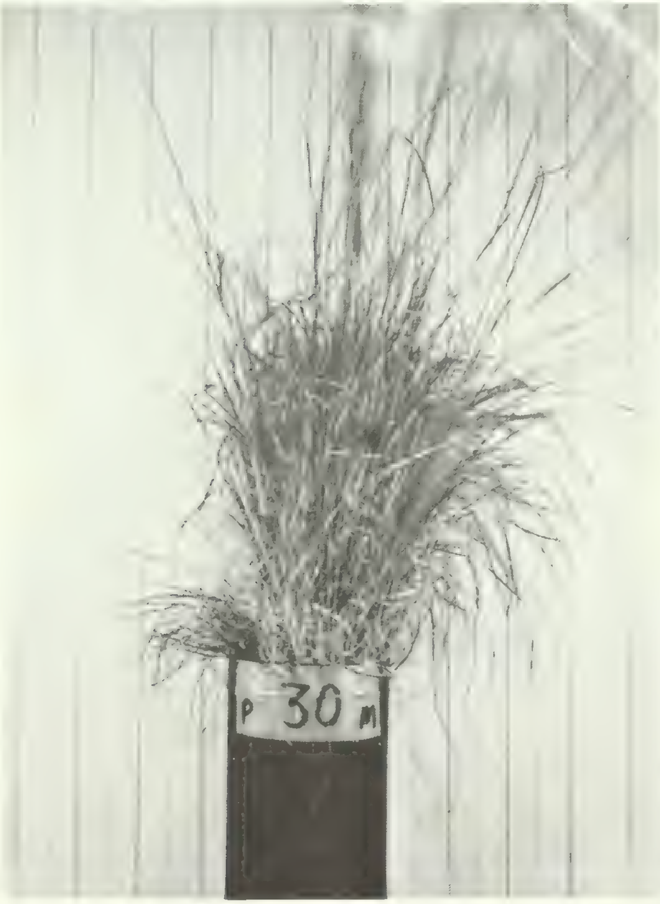

Figure 5.—The pine-muhly species combination, planted simultaneously (Group A), at age 9 months. Competition for growing space occurred as early as 3 months into the experiment.

Table 1.--Comparative growth of ponderosa pine, Arizona fescue, and mountain muhly

Group	Species evaluated	Species combination	Mean total height	Mean top dry weight	Mean root dry weight	Mean top/root weight ratio	Pine mean foliage height	Grass mean top volume
			cm	*g*	*g*		*cm*	*cm*^{3}
GROUP A[1]	Ponderosa pine	Pine/Pine	20.0	0.75	0.26	3.96	17.5	
		Pine/Fescue	16.8	.49	.14	3.79	14.3	
		Pine/Muhly	16.7	.55	.24	3.27	14.2	
	Arizona fescue	Fescue/Fescue	67.8	8.82	7.07	1.52		259.5
		Fescue/Pine	64.0	13.60*	11.09*	1.56		376.9*
		Fescue/Muhly	61.2	7.79	4.18	1.98		216.2
	Mountain muhly	Muhly/Muhly	57.0**	18.38	7.31	4.43		275.1
		Muhly/Pine	69.3	35.47	9.93	3.95		585.0*
		Muhly/Fescue	68.2	32.73	7.14	5.25		460.5
GROUP B[2]	Ponderosa pine	Pine/Pine	19.5 a	1.34 a	0.60 a	2.26	17.0 a	
		Pine/Fescue	19.6 a	1.55 a	.68 a	2.30	17.1 aj	
		Pine/Muhly	24.2 a	1.80 a	.94 a	1.99	21.7 ai	
		Pine/Pine	7.2 be	.12 b	.06 b	3.13 e	5.3 be	
		Fescue/Pine	4.2 bf	.02 b	.01 b	1.75 f	2.9 bf	
		Muhly/Pine	.0 bf	.00 b	.00 b	.00 f	.0 bf	
	Arizona fescue	Fescue/Pine	67.8 a	18.86 a	21.65 a	.98 a		447.5 a
		Fescue/Fescue	63.0 a	20.35 a	25.63 a	.89 a		526.5 a
		Fescue/Muhly	68.2 a	20.78 a	18.70 a	1.46 a		503.9 a
		Pine/Fescue	37.7 beg	.39 b	.66 b	.63 b		3.4 b
		Fescue/Fescue	.0 bf	.00 b	.00 b	.00 b		.0 b
		Muhly/Fescue	.0 bfh	.00 b	.00 b	.00 b		.0 b
	Mountain muhly	Muhly/Pine	71.4 a	40.42 a	11.42 a	3.67 a		695.5 a
		Muhly/Fescue	73.9 a	43.80 a	13.66 a	3.52 a		713.5 a
		Muhly/Muhly	75.6 a	42.71 a	13.66 a	3.91 a		709.2 a
		Pine/Muhly	23.4 beg	.80 b	.35 b	2.00 bg		8.4 b
		Fescue/Muhly	.0 bfh	.00 b	.00 b	.00 bh		.0 b
		Muhly/Muhly	.0 bf	.00 b	.00 b	.00 b		.0 b

* Differs significantly from other two members of group at 5 percent level.

** Differs significantly from other two members of group at 2.5 percent level.

[1] Three species planted simultaneously in various combinations; plants grown for 9 months in controlled environment.

[2] Three species planted at different times in various combinations; second species planted 3 months after first. Species left of / planted early; species right of / planted 3 months later.

Comparison	Interpretation
a,a,a *vs.* b,b,b	Collectively, early-planted species combinations (a,a,a) differ significantly from late-planted species combinations (b,b,b).
e *vs.* f,f	Pine or grass species planted late with an existing pine (e) differs significantly from the same species planted late with an existing grass plant, considered collectively (f,f).
g *vs.* h	Fescue or muhly planted late with an existing pine (g) differs significantly from fescue or muhly planted late with the alternate grass species (h).
i *vs.* j	Pine planted early with muhly (i) differs significantly from pine planted early with fescue (j).

related to the difference in growth. Muhly plants were significantly shorter when associated with another muhly and had only half as much top volume after 9 months compared to muhly plants associated with pines.

Data for Group B (table 1) and interpretation of significant specific comparisons show that the responses generally, are the same as in Group A. In all cases, except mean top/root weight ratio of pine, plants of the species evaluated established early (a,a,a) collectively differed significantly from plants established 3 months later (b,b,b). This is an expected difference due to the difference in age of the plants. The top/root weight ratio of the grasses apparently changes with age, as indicated by the difference between early- (a,a,a) and late-planted (b,b,b) seedlings. Pine or grass seedlings established late with an existing pine seedling (e) demonstrated superior height growth compared to seedlings planted late with the two grasses considered collectively (f,f).

Considering the grasses independently, fescue or muhly seedlings planted late with an existing pine (g) grew taller than when planted late with the other grass species (h). Although the significant (e) vs (f,f) and (g) vs (h) comparisons might be considered meaningless because of almost complete mortality of seedlings planted late with an existing grass plant, they are important in that they depict the intense vegetative competition expressed by an established grass plant. Finally, pines planted early with muhly (i) had significantly greater foliage height than when planted early with fescue (j). A similar difference developed in mean total height of pines, but is not significant due to high variation. In all cases, the observed effects can be ascribed to the lack of competition because of the presence of a pine seedling, or conversely, due to intense competition from an existing grass plant. Muhly appears to be slightly less competitive toward the pines than fescue.

There were no significant differences in germination of yellow sweetclover seeds incubated either in leachate from pots representing the species combinations in Group A or distilled water, indicating no detectable amount of inhibitory substance arising from grass roots was leached from the pots.

Seed Germination in Leachates From Grass Residues

The results of the extract experiment indicated that a phytotoxic substance is contained in the residues of grass plants, and is particularly concentrated in live foliage. In this experiment, leaching from live foliage was explored as a possible route of release of the inhibitor.

Materials and Methods

Samples of fescue and muhly live grass blades and seedstalks were collected in mid-September on the Fort Valley Experimental Forest. Fescue stalks had begun to dry when collected, whereas muhly stalks were still green; blades of both species were green. In the laboratory, the samples were separated into seedstalks and blades. A 50 g sample (fresh weight) of each of the four residue types was soaked in 100 ml of distilled water in a large beaker for either 5 minutes or 12 hours. Each was agitated for 5 minutes to wet all of the material. At the end of the soaking periods the eight leachates were drained off and refrigerated.

Surface-sterilized pine seeds were used to test the leachates for phytotoxicity. Ten ml of leachate were transferred to each of three 9 cm petri dishes, evaporated to dryness, autoclaved, and cooled. In a separate test, it was found that autoclaving grass residue extracts did not alter their growth-inhibiting potential. Three ml of sterile distilled water and 100 unstratified surface-sterilized seeds were added to each petri dish. Germination tests were conducted in darkness in a small Mangelsdorf germinator with temperature set at 75°F and high humidity. Other procedures and germination criteria were the same as described previously. The number of germinated seeds was recorded daily for 11 days. From these data, percentage germination and speed of germination were calculated and tested for significant differences by analysis of variance.

Results and Discussion

None of the leachates affected percentage germination or speed of germination of pine seed. Seeds germinating in the 12-hour leachates exhibited the same appearance symptoms as in the extract experiment. The dark brown sheaths at the root collar and radicle tip may simply be the result of staining by the extract or leachate.

Overwintering of Pine Seeds Under Various Plant Residues

Newly fallen pine seeds normally lie on the ground in the presence of grass and pine residues until the following July, 8 months or more, before environmental conditions are right for germination. In this experiment, samples of ponderosa pine seed were overwintered under various plant residues in different stages of decomposition to determine if continuous exposure to leachates of plant residues over the natural period would adversely affect seed viability.

Materials and Methods

Fescue, muhly, and pine residues were collected on the Fort Valley Experimental Forest in mid-November. The grasses had entered dormancy by that time, so the residues collected were FNL, FOL, FR, MNL, MOL, MR (all described in the extract experiment), plus freshly fallen pine needles (PNL) and partially decomposed pine needles (POL). All of the residues were chopped into smaller pieces so they would form a dense mat over the seeds.

The experiment was conducted at the Fort Valley Experimental Nursery, which is surrounded by a rodentproof fence (fig. 6). The area utilized had been kept free of vegetation, including conifers, for several years. The soil surface was leveled and covered with approximately 2 inches of washed sand to eliminate interference from substances in the soil. Thirty-six metal retaining rings 12 inches in diameter and 2 nches deep were arranged in a grid pattern on the sand with 2 feet between rings. The rings were randomly assigned to treatment.

Approximately 225 ponderosa pine seeds, measured by weight, were evenly distributed on top of the sand in the retaining rings and covered with the predetermined type of residue to the top of the ring. The control treatment consisted of rings filled with washed sand. Each ring was covered with a square of ½-inch hardware cloth for further protection.

On June 5 the seeds were recovered from the ndividual retaining rings. They were not washed before the germination test, but were shaken on a screen to remove extraneous materials. One hundred seeds from each replication were germinated in a 9 cm petri dish under the same conditions as the extract experiment. The seeds were wetted with a minimum amount of sterile distilled water. Germination was recorded daily; seeds were considered germinated when radicle length equaled the length of the seed. Locations of dishes in the growth chamber were randomized after each germination count. After 18 days the ungerminated seeds were cut to determine soundness. Percentage germination data, based on sound seeds, were tested for significant differences by analysis of variance.

Results and Discussion

The winter of 1969-70 was an "open winter" with only 9.74 inches of precipitation during the period November 20 to June 5; 7.14 inches of this total fell during March. Consequently, during most of the winter there was only minimal moisture available for leaching.

There were no significant differences in percentage germination of pine seeds overwintered under the different plant residues:

Type of residue	Percentage germination
FNL	89.0
FOL	85.4
FR	85.7
MNL	88.5
MOL	89.1
MR	79.7
PNL	90.5
POL	88.4
Control	92.6

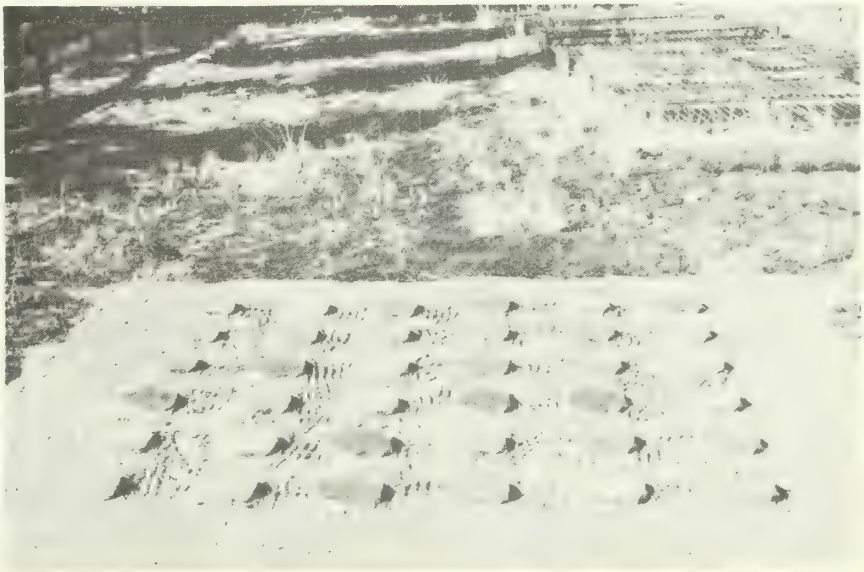

Figure 6.—Pine seeds were overwintered under various residues of pine, fescue, and muhly. The seeds were recovered and germinated the following summer.

The germination in each case was quite high, indicating no general loss of viability due to the treatments.

These results do not agree with findings from an informal study conducted in the winter of 1956-57 (USDA-FS 1957). Pine seeds overwintered under Arizona fescue litter yielded 63 percent germination the following summer, compared to 85 percent for pine needle litter and 87 percent for no cover. Leaching conditions were somewhat better during the period November to June 1956-57, with 12.27 inches of precipitation, of which 6.17 inches fell during January. Furthermore, seeds were placed directly on the surface of a clay soil, which potentially would allow some accumulation of leached substances. Such accumulation would be unlikely in the sand layer used in the present experiment.

DISCUSSION OF ECOLOGICAL SIGNIFICANCE

The route of release of the inhibitory substance remains uncertain, in spite of several efforts to identify a pathway. Release of the inhibitor underground as a root excretion can probably be ruled out, judging from the lack of any evidence pointing to chemical effects in the sand culture experiment, and since an extraction of fescue and muhly roots was not inhibitory in the extract experiment. The inhibitory substance is apparently present in aboveground grass residues and most concentrated in live, green foliage.

The question reduces to: how is the inhibitor released to the external environment, and how does it enter the receiver species? Since little microbial decomposition occurs in standing dead residues, the principal mechanisms of breakdown would be biochemical degradation during senescence, and normal weathering processes. Any inhibitory substance in the standing residues at the time senescence begins would subsequently (1) undergo biochemical degradation, (2) oxidize as a result of weathering processes, or (3) remain intact for some indefinite period. The principal processes for removal of breakdown products or an intact inhibitor would be translocation, volatilization, or leaching.

Overwinter leaching does not appear to be the route of release, unless there is accumulation in the soil up to and during the time of germination and growth of the receiver species. Considering the high water solubility and probable subjectivity to microbial decomposition, it is unlikely that the inhibitor could persist, even in clay soils, until the following July. Leaching should not be ruled out, but it appears that leaching at or near the time of seed germination and initial growth of the receiver species is more likely to be effective. Leachates prepared from mid-September live foliage and new litter of fescue and muhly were not toxic to germinating pine seeds, however. To fully understand the role of leaching as a route of release, research is needed on the presence, toxicity, and leachability of the inhibitor in live and dead grass residues during the growth period of the receiver species.

A potential mechanism of release of the inhibitor which was not studied is the formation of phytotoxic substances during microbial decomposition of dead residues on or in the soil. The liberation of substances toxic to living plants during decomposition of plant residues appears to be a widespread phenomenon (McCalla and Haskins 1964, Patrick 1971, Patrick and Koch 1958, Patrick, Toussoun, and Koch 1964). Soil toxicity due to decomposition of organic constituents is most frequently associated with heavy, poorly aerated, or waterlogged soils. However, localized pockets of anaerobiosis are widespread in the soil and may prevail for varying periods of time following rainfall (Patrick 1971). Conditions that lead to the formation of high concentrations of phytotoxic decomposition products may, therefore, be more common than is generally realized, and not necessarily confined to waterlogged soils. Additional research is needed on microbial decomposition of dead residues on or in the soil as a possible mechanism of release of the inhibitor.

There is evidence to suggest that the inhibitor must be present at a time of physiological activity (germination and initial development) of the receiver species in order to be effective. Extracts prepared from FF, FNL, and MF residues significantly depressed germination of ponderosa pine seeds in the extract experiment (fig. 1), whereas similar residues collected 2 months later had no effect on germination of pine seeds in the overwintering experiment. The newer grass residues employed in the overwintering experiment must have contained a considerable amount of the inhibitor,[5] but overwinter exposure of dormant pine seeds to the inhibitory substance leached from the residues did not have any effect on germination in distilled water the following summer.

The results of the followup experiment in which a postgermination addition of extract from fescue foliage retarded radicle elongation of pine seedlings further supports this suggestion. This point could be clarified by (1) a study on low-temperature soaking of seeds in fescue foliage extracts and subsequent germination (after rinsing) in distilled water at a higher temperature, and (2) a study to determine if the effects of the inhibitor can be reversed.

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[5] *FNL in the extract experiment had been dead nearly 12 months, whereas the residue designated FNL in the overwinter leaching experiment had been dead only 2 months.*

An important question that should be considered s the relation between the amounts of the residues sed to prepare the extracts in the experiments and he amounts that occur in nature in an arbitrary area f influence around a single seed. The amount of erbage production depends upon the extent of tree over. Arnold (1956) estimated that herbage prouction would vary from 1,000 pounds dry weight er acre per year in forest openings to 50 pounds per cre per year under dense forest canopies. In these penings, assuming no grass utilization, the potential ddition of residues to the soil each year is 1,000 ounds dry weight per acre. If 1 square inch is onservatively estimated to be the area of influence round a single pine seed, then an average of 0.072 g f grass residue would be introduced into this area ach year. In the extract experiment, 5 ml of extract btained from 0.67 g of dry residue (extract yield rom 20 g of residue and 200 ml of water was 150 ml) as sufficient to produce the reported effects in 100 eeds, which is equivalent to 0.0067 g of residue per eed. The followup experiment utilizing sterilized xtracts found that 0.004 g of residue per seed was nhibitory. Dividing the yearly production of 0.072 g f residue per 1 square inch by the calculated xperimental rate per seed shows that 10.8 times as nuch residue is added to the area of influence per ear than was necessary to induce the observed ffects in the extract experiment.

These calculations serve only to illustrate that the mount of the residues used to prepare the extracts is onservative compared to the amounts that occur in ature. The primary difference between the two cases s the concentration of inhibitor around a seed at any ne time. In the extract experiment, the inhibitory ubstance contained in the residues was almost ompletely released into solution at one time, hereas in nature the phytotoxins are undoubtedly eleased more slowly. Under natural conditions, even hough greater amounts of residues may occur, the oncentration of inhibitor at a particular time may ot approach that of the extract experiment. The net nfluence of plant sensitivity to the inhibitor and the ffect of interacting environmental variables that ffect the concentration of inhibitor present would etermine the extent of allelopathy. At this time we an only state that there is potential for allelopathy n the ponderosa pine — bunchgrass community.

Allelopathic effects would be conditioned by a host f factors, including the route and rate of release of he inhibitor, timing of release with growth processes f the receiving species, persistence of the inhibitor n the soil, distribution of seeds and residues, and eather conditions. The outcome of interactions mong these environmental factors could vary within road limits, ranging from striking examples of llelopathy to fluctuations or chronic expressions, or o effect at all. Furthermore, it is entirely possible that the existing severe competition for water, nutrients, and growing space (Larson and Schubert 1969b) is the near-total mechanism.

If allelopathy occurs in the ponderosa pine — bunchgrass community of northern Arizona, what is its ecological role? The grasses are superior competitors for available water and nutrients (Larson and Schubert 1969b), and the sand culture experiment indicated they also compete successfully for growing space. These characteristics alone would seem to enable the grasses to dominate the site. But they do not explain the observed phenomenon where bunchgrasses have persisted on a site for 100 years or more (Schubert 1974), encompassing numerous seed crops and moist periods that are suitable for the establishment of pines. But no new pines emerge unless the grass cover is disturbed. The combined effects of an allelopathic mechanism and plant competition is a more feasible explanation for the long-term exclusion of new pine seedlings and other species from the community. Therefore, allelopathy may prolong the bunchgrass successional stage and forestall the ponderosa pine climax.

CONCLUSIONS

A growth-inhibitory substance is produced predominantly in live foliage, and to a lesser extent in dead residues, of Arizona fescue and mountain muhly in the northern Arizona ponderosa pine — bunchgrass community. The inhibitor is capable of substantially reducing total germination and retarding germination rate and initial radicle development of ponderosa pine. The osmotic potential of the extracts confounds to some extent their phytotoxic effects.

The route of release of the inhibitor remains uncertain, although three possible routes were studied. Neither winter-long leaching of dead residues nor root excretion appears to be the principal route of release. Since dormant seeds and seedlings are insensitive to the inhibitor, it was suggested that leaching from live grass tissues and release of substances by microbial decomposition of dead residues during the growing season are potentially significant routes of release. Further research is recommended on these pathways.

Further research is also needed to clarify the ecological significance of the inhibitor. On the basis of the concentrations found toxic in laboratory experiments, there is considerable potential for toxic concentrations to occur under natural conditions. Actual inhibitory effects would be conditioned by a number of environmental variables, including those which (1) affect the rates of leaching and residue decomposition, and (2) influence the persistence or rate of degradation of the free inhibitory substance in the soil. Coincidence of toxic levels of the inhibitor with initial growth processes appears to be necessary.

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Extracts of green foliage of Arizona fescue and mountain muhly significantly reduced germination of ponderosa pine seeds, and retarded speed of elongation and mean radicle length. Three possible routes of release of the inhibitor were investigated: (1) leaching from live foliage, (2) root exudation, and (3) overwinter leaching from dead residues. The principal route remains uncertain. The ecological implications of the inhibitory substance are discussed.

Keywords: *Muhlenbergia montana* (Nutt.) Hitchc., *Festuca arizonica* Vasey, *Pinus ponderosa* Laws., allelopathy, phytotoxic substances, plant competition, chemical ecology.

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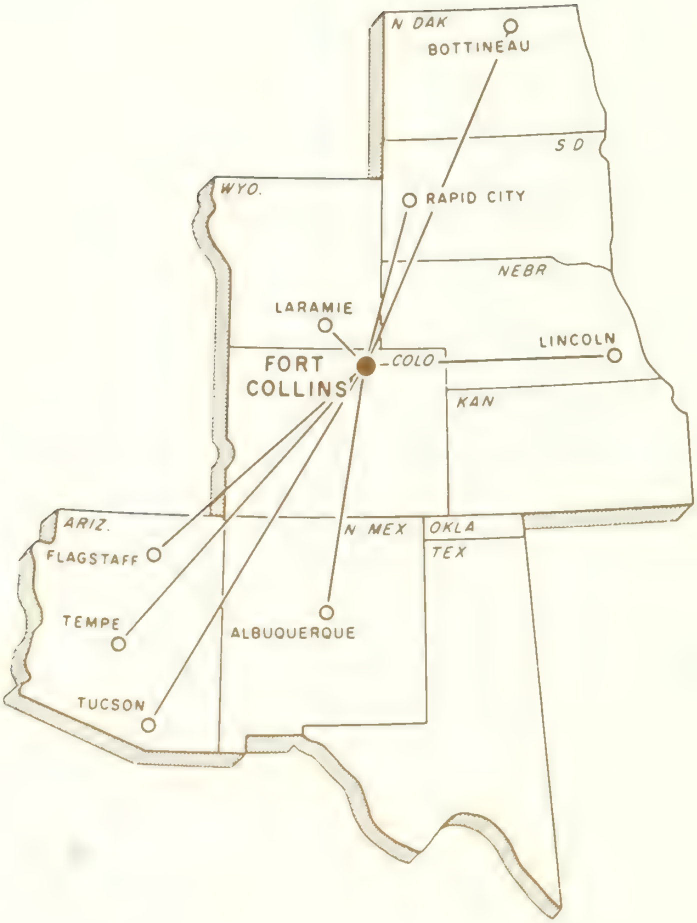
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Range
Management
in the
Central
and
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Rocky Mountains:

A Summary
of the
Status
of Our
Knowledge
by
Range Ecosystems

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Harold A. Paulsen, Jr.

USDA Forest Service
Research Paper RM-154
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521
October 1975

Abstract

Summarizes a series of comprehensive reports on range management in the seven recognized ecosystems: Semidesert grass-shrub, southwestern chaparral, pinyon-juniper, central Rockies ponderosa pine-bunchgrass, Arizona ponderosa pine-bunchgrass, mountain grassland, and alpine. Includes what is known, what can be recommended, and what additional information is needed for each ecosystem.

Keywords: Range ecosystems, semidesert grass-shrub, southwestern chaparral, pinyon-juniper, central Rockies ponderosa pine-bunchgrass, Arizona ponderosa pine-bunchgrass, mountain grassland, alpine.

SDA Forest Service
esearch Paper RM-154

October 1975

RANGE MANAGEMENT IN THE CENTRAL AND SOUTHERN ROCKY MOUNTAINS:

A Summary of the Status of Our Knowledge by Range Ecosystems

Harold A. Paulsen, Jr.
Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

PREFACE

Seven comprehensive, in-depth reports drawn from the current literature on range management have been prepared by range scientists of the Rocky Mountain Forest and Range Experiment Station for the important range types in the central and southern Rocky Mountains. These reports have been condensed and arranged in a common format here to provide a summary of information that is available to the range managers, and is especially applicable for range management in the seven recognized ecosystems. Only those literature citations not included in the full-length papers are mentioned in this summary.

We recognize there also exists a considerable body of valuable range management knowledge that has been accumulated through experience and familiarity with specific range situations. This knowledge permits a higher degree of sophistication of range management in local areas, but such information is not generally available in the published literature. Individual reports are as follows:

Semidesert Grass-Shrub Ecosystem—

"Ecology and management of southwestern semidesert grass-shrub ranges: The status of our knowledge," by S. Clark Martin (RM-156).

Southwest Chaparral Ecosystem—

"Range management in the chaparral type and its ecological basis: The status of our knowledge," by Dwight R. Cable (RM-155).

Pinyon-Juniper Woodland Ecosystem—

"Characteristics and management of southwestern pinyon-juniper ranges: The status of our knowledge," by H. W. Springfield (RM-160).

Central Rockies Ponderosa Pine-Bunchgrass Ecosystem—

"Grazing management of ponderosa pine-bunchgrass ranges of the central Rocky Mountains: The status of our knowledge," by Pat O. Currie (RM-159).

Arizona Ponderosa Pine-Bunchgrass Ecosystem—

"Range management and its ecological basis in the ponderosa pine type of Arizona: The status of our knowledge," by Warren P. Clary (RM-158).

Mountain Grassland Ecosystem—

"Management of mountain grassland: The status of our knowledge," by George T. Turner (RM-161).

Alpine Ecosystem—

"Alpine range management in the western United States—principles, practices, and problems: The status of our knowledge," by John F. Thilenius (RM-157).

CONTENTS

Page

INTRODUCTION 1

SEMIDESERT GRASS-SHRUB ECOSYSTEM 3
  General Characteristics 3
  Range Management Prescriptions 4
    Stocking and Forage Use 4
    Grazing Systems 5
    Range Improvement Practices 6
    Improving Livestock Distribution 7
  Additional Needed Guidelines 7

SOUTHWEST CHAPARRAL ECOSYSTEM 8
  General Characteristics 8
  Range Management Prescriptions 9
    Stocking and Forage Use 9
    Grazing Systems 9
    Range Improvement Practices 9
  Additional Needed Guidelines 11

PINYON-JUNIPER ECOSYSTEM 13
  General Characteristics 13
  Range Management Prescriptions 14
    Stocking and Forage Use 14
    Grazing Systems 14
    Range Improvement Practices 14
  Additional Needed Guidelines 17

CENTRAL ROCKIES PONDEROSA PINE-BUNCHGRASS ECOSYSTEM 18
  General Characteristics 18
  Range Management Prescriptions 19
    Stocking and Forage Use 19
    Grazing Systems 19
    Range Improvement Practices 19
  Additional Needed Guidelines 21

ARIZONA PONDEROSA PINE-BUNCHGRASS ECOSYSTEM 22
  General Characteristics 22
  Range Management Prescriptions 23
    Stocking and Forage Use 23
    Grazing Systems 24
    Range Improvement Practices 24
  Additional Needed Guidelines 25

Page

MOUNTAIN GRASSLAND ECOSYSTEM 26
  General Characteristics 26
  Range Management Prescriptions 27
    Stocking and Forage Use 27
    Grazing Systems 28
    Range Improvement Practices 28
  Additional Needed Guidelines 29

ALPINE ECOSYSTEM 30
  General Characteristics 30
  Range Management Prescriptions 31
    Stocking and Forage Use 31
    Grazing Systems 31
    Range Improvement Practices 32
  Additional Needed Guidelines 32

RANGE RESOURCE PRIORITY PROBLEMS 33

LITERATURE CITED 34

RANGE MANAGEMENT IN THE CENTRAL AND SOUTHERN ROCKY MOUNTAINS:

A Summary of the State of Our Knowledge by Range Ecosystems

Harold A. Paulsen, Jr.

INTRODUCTION

In addition to the intrinsic characteristics of the ite, four factors affect the management of any range rea—economics, social pressures, multi-purpose emands, and the availability and acceptance of new nowledge. Traditionally, the term "range" has been ssociated with cattle and sheep grazing, which ecame prominent in the western United States in he last quarter of the 19th century. More recently, angelands have become increasingly important for dditional values, although domestic livestock grazng continues to be a significant element.

Through more than 70 years of research and mangement experience, sound techniques and informaional guidelines have been developed which provide he basis for range management under domestic vestock use. Pertinent information can be found on he ecology and management of most major range nd forest-range ecosystems. However, today's land nanager must direct his effort within multiple use onstraints; the view that rangelands are primarily he domain of the livestock industry is no longer enable.

Rangelands are commonly recognized as uncultiated areas that support herbaceous or shrubby vegeation; they may or may not have a tree overstory. The angeland complex encompasses the vegetation, soil, tmosphere, water, and animal life. Although most anges are characterized by native plants, extensive reas have been seeded to exotic species to increase orage production and improve range condition.

In general, ranges have relatively low biological roductivity (Clawson 1972),[2] and hence are someimes referred to as economic residuals after more roductive sites were converted to higher economic ses such as improved pastures and croplands. While limited plant growth is typical of most ranges, rough topography, remoteness, shallow soil, low rainfall, and severe temperatures are also frequently implicit in the concept of rangelands (Thomas and Ronningen 1965). Additionally, socioeconomic factors further complicate the manager's task.

Efforts to improve rangeland productivity must often be restricted because of economic considerations. Only relatively inexpensive means can be employed, and these must be amortized over long periods. Likewise, economic constraints limit the research that can be justified, particularly in grazing experiments where large areas of land are needed to provide the necessary replications (Thomas and Ronningen 1965).

From the national viewpoint, livestock production on rangelands is but a modest part of today's total commercial agriculture (Blaisdell et al. 1970). Nevertheless, grazing of rangelands by domestic or wild herbivores converts a product (forage) that otherwise would not be utilized. Furthermore, of the energy garnered from the sun, about 10,000 calories of fossil fuel per person per day are expended to harvest about 3,000 calories stored in foods grown on cultivated lands (Thomas 1971). In contrast, the fossil fuel requirements for livestock production on rangelands is very small. Thus, critics who contend that we cannot afford to convert plant products into animal products must recognize that ruminant animals subsist in large part upon matter which, if not utilized, would lower the earth's total food-producing potential (Van Horn et al. 1972).

However, to consider rangelands only in the context of livestock production is simplistic. Society has an interest in these lands from a multiple use standpoint, and in some areas social considerations outweigh direct income alternatives (Thomas and Ronningen 1965). Nevertheless, the economic fabric and social well-being of many rural areas are heavily dependent on and oriented toward rangeland livestock operations.

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[2] *Only those literature citations not included in the full-ength papers are mentioned in this summary.*

Moreover, in our present society, absentee owners, land speculators, miners, sportsmen, and other recreationists are claiming an increasing voice in what happens on the land. Recent public concerns about esthetics, habitat destruction, or the balance of nature, have influenced policies of public land administration and the use of private lands as well. Added to these concerns is the loss of land to other uses such as surface mining and residential subdivisions.

In many cases, however, herbage and browse on rangeland can contribute far more feed for livestock and wildlife than it now provides. Increased understanding of the interrelationships among the plants, animals, and their environment is of fundamental significance if we are to realize the full potential of the nation's range resource. It has been optimistically predicted that future research could lead to techniques for doubling or even tripling the productivity of rangelands (Thomas and Ronningen 1965). For example, beef production has been more than doubled on seeded-native range combinations at the Eastern Colorado Range Research Center (Denham 1973).

One of two major purposes of this paper is to provide a compendium of information for the land manager faced with managing the range resource of the central and southern Rocky Mountains. The second is to identify gaps in our knowledge which handicap prudent usage of the range resource.

The major biotic and abiotic attributes of seven range ecosystems are highlighted, and management practices that have proved feasible are described. Where a lack of knowledge forestalls sound resource management, the needed research has been identified by priority.

The seven range (including forest-range) ecosystems described encompass over 150 million acres in Arizona, New Mexico, west Texas, Colorado, Wyoming, and the Black Hills. They comprise about 12 percent of the pasture and native grazing lands of the United States. Recognized are semidesert grass-shrub, chaparral, pinyon-juniper, central Rockies ponderosa pine-bunchgrass, Arizona ponderosa pine-bunchgrass, mountain grassland associated with subalpine forests, and alpine grasslands. Three additional ecosystems contribute substantially to the total range acreage of the entire region: the shortgrass plains and sandhills, sagebrush-grass, and southern desert shrub.

The pattern of land ownership, type of ranching operation, and the demands on the range resources differ markedly from the lower elevations to the high mountains. Much of the land area is in federal ownership, railroads hold title to millions of acres, and additional vast acreages are in State lands. Biological features are characterized by wide diversity in plants and wildlife. Extremely wide differences in elevation, climate, geology, and other physical characteristics add to the complexity of management.

Dispersed in each of the seven ecosystems are plant communities associated with high moisture regimes. The riparian and phreatophyte vegetation found along watercourses and around the perimeter of natural or manmade lakes and on flood plains is often the most productive of any ecosystem. Unfortunately, this vegetation is also often the most severely overused and depleted. Concentrations of livestock coupled with direct or indirect human activities have materially altered their inherent productive capability and created many downstream problems. Overgrazing has resulted in depletion of the vegetation and cutting of the stream channel. Lowering of the water table has converted plant communities to species that require less water for survival, but also are less productive. Diversion of water from the streams for irrigation use, coupled with the high recreation value of water-related sites, have compounded the problems.

Flood plains have been converted to farmlands or improved pasture thereby altering their ecological niche and possibly increasing their economic worth. However, other intangible values that depend on the natural state of these ecosystems may be irretrievably lost. For example, their significance to wildlife including fish, recreation, esthetics, and preservation of natural areas must be recognized in multiple use management.

The management of riparian and phreatophyte ecosystems is inseparable from the management of adjacent ecosystems that have been more fully treated here, although special consideration is required to preserve or improve them.

General Characteristics

The Southwestern semidesert grass-shrub ecosystem occurs in a discontinuous belt 50 to 100 miles wide as arid grasslands intermingled with shrubby or low trees on the broad flat valleys and ower mountain slopes, generally at elevations between 3,000 and 5,000 feet. It occupies nearly 60 million acres, largely in western Texas and the southern parts of Arizona and New Mexico, where it s in close contact with the southern desert shrub type and the shortgrass plains (fig. 1).

The major vegetation communities include mixed grama grasslands, flood plains of tobosa [3] or sacaton, and mesquite-grasslands (fig. 1). Additionally, several shrub-dominated communities with affinity to he lower desert shrub ecosystem may be found.

The entire semidesert region has significantly changed in the last 100 years. Grazing by domestic animals has reduced the abundance of preferred forage species, which have been replaced by plants that are less palatable to livestock. For example, shrubs, unpalatable forbs, and annual or short-lived perennial grasses are characteristic of ranges that have suffered past abuse. Invasion by these species usually have been accompanied by decreased forage production and increased soil erosion. They are indicators of mismanagement and disruption of the ecological balance that had previously kept them in check.

The climate is characterized by mild winters and hot summers. Annual precipitation may reach 20 inches, but at least half of the area receives little more than 10 inches per year. There are two distinct rainy periods, one in summer and one in winter; the percentage of the annual precipitation received in the summer increases from west to east.

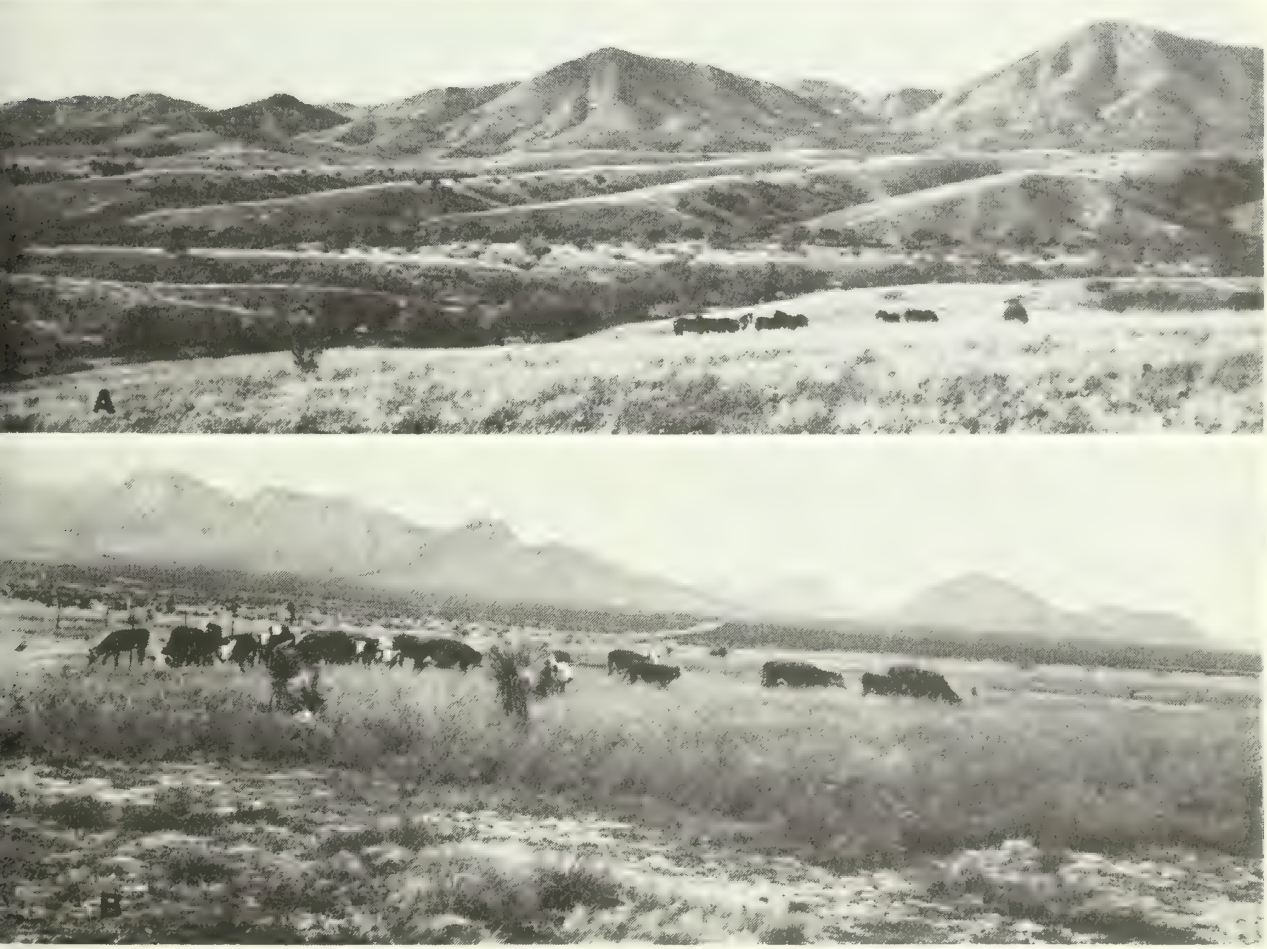

Figure 1.—Semidesert grass-shrub types: **A**, Mixed grama grassland interspersed with mesquite trees; **B**, Dense stand of tobosa on a swale with heavy clay soils.

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[3] *Common and scientific names of specific plants mentioned are listed at the end of the individual full-length papers.*

Forage production depends on summer rains, which usually begin around mid-July in the central portion of the type. These rains produce about 90 percent of the forage, which consists mainly of perennial grasses; certain browse species and annual grasses are sometimes important.

The seasonal distribution of precipitation significantly affects plant growth, and must be recognized in grazing management. Although perennial grasses produce only a small amount of herbage in March and April, this growth is often critical to the subsequent production of forage the following summer. Culms that make the bulk of their growth in response to the summer rains originate during the preceding spring or fall. Two consecutive summers with ample, well-distributed rainfall can be expected to produce high forage yields because of this sequence of culm initiation and growth proliferation. However, wide fluctuations in precipitation are common, with consequent great year-to-year variations in forage production.

Semidesert grass-shrub ranges are grazed mainly by cattle. The nutritive quality of most forage species is adequate for them during the growing period, but perennial grasses are usually deficient in protein, phosphorus, and vitamin A by midwinter. On ranges where there is a mixture of grasses and palatable shrubs, cattle can usually select a diet that is adequate in protein in all but the coldest part of the year.

Most semidesert ranches are cow-calf operations. Calves are born in early spring and sold when they are weaned in late fall. This schedule coincides with the growth of forage. Calves are large enough to take their mother's increased milk production during the flush of growth, and usually are as heavy by late fall as they will be 6 to 8 months later after being weaned and wintered on the range.

Ranges better suited to yearlings or steers than to cows and calves include rough or rocky areas that are better used by lighter, more active animals, and remote or brushy ranges where losses of young calves to predators might otherwise be excessive.

Semidesert ranges support a variety of wildlife. Increased shrub cover on some semidesert ranges has improved the habitat for deer at the expense of forage production for cattle. In some areas it has been more profitable to manage a range to produce a mixture of wildlife and livestock, where substantial income can be obtained from the sale of hunting privileges. Other recreational activities in the semidesert range ecosystem are becoming popular among urban residents of the region or winter tourists.

Flexible stocking is often recommended for semidesert ranges because forage production varies greatly from year to year. For cow-calf operations, the breeding herd probably should be kept at less than 70 percent of the average capacity for the range; extra forage in good years could be utilized by carrying over extra yearlings. In years of low production, the normal complement of yearlings would be sold and only the breeding herd would be kept. A serious shortcoming of this plan is that each year's forage crop is not known until the growing season is over. If extra calves are kept on the range following a good summer forage crop, they should be sold the following spring. If the extra animals are not sold in May or June, the range may be overstocked during the next growing season (July-September). In most years holding calves only until spring is not profitable because weaner calves gain little in weight or value from November 1 to May 31.

If calves are held over until the fall of their second year they normally will have gained 200 or more pounds and usually be worth about one-third more than they were as calves. A recent evaluation of various stocking plans for southern Arizona range showed that net sales per animal unit of stocking were lower for cow-yearlings than for cow-calf operations. This study showed that net sales were highest when the breeding was maximized, and that constant stocking at 90 percent of average carrying capacity was much less risky than flexible stocking and produced almost as much income.

Semidesert ranges are better suited for producing calves than for putting weight on yearlings because semidesert forage produces rapid weight gains only during the summer growing season. Holdover yearlings mark time for 8 or 9 months (November-June), then make all of their gain for the year during a period of 3 or 4 months. Income per animal unit of average stocking usually is less for cow-yearling production than for cow-calf production. Exceptions do occur, however, as when feed costs are so high that feeders pay more per pound for a 650-pound yearling than for a 400-pound calf. Continued high feed prices could shift the advantage from cow-calf to cow-yearling production. This would increase the relative contribution of range forage to finished beef, but would reduce the number of animals produced and decrease total beef production for the region.

Range Management Prescriptions

Stocking and Forage Use

As a basic premise, management of semidesert grass-shrub ranges should be focused on maintaining or developing productive stands of perennial grasses, which are the most reliable and productive component of the forage resource. Traditionally, these ranges have been grazed yearlong. Annual stocking has varied widely because of large fluctuations in forage production. As a rule of thumb, however, the number of cattle grazed should utilize about 40 per

Table 1.--Estimated average yearlong stocking rate, by condition class, for semidesert grass-shrub range

Elevation (Feet)	Precipitation	Range condition class					
		Very poor[1]		Poor and fair		Good and excellent	
	Inches	*Animals/ square mile*	*Acres/ animal*	*Animals/ square mile*	*Acres/ animal*	*Animals/ square mile*	*Acres/ animal*
High (4,000-5,000)	16+	<12	>50	15-18	35- 45	18-25	25- 35
Intermediate (3,300-4,000)	12-16	<6	>100	6-12	50-100	12-16	40- 50
Low (Less than 3,300)	12	<4	>160	4- 6	100-160	6-10	60-100

[1] < signifies less than; > signifies more than.

cent of the perennial grass production in an "average" year. This guideline applies to land that is nherently suitable[4] for livestock grazing and is in fair or better range condition. Average yearlong stocking rates developed on the Santa Rita Experimental Range apply for most semidesert ranges suitable for cattle grazing (table 1).

Grazing Systems

Research and experience have shown that continuous yearlong grazing results in overuse of the forage and deterioration of the forage stand in areas of livestock concentration, while forage in remote parts of the range is largely unused. Still, if average utilization of the most important perennial grasses over the entire range unit does not exceed 40 percent at the end of the grazing year, immediately before the flush of new growth from summer rains begin, continuous yearlong grazing is less destructive than some of the alternatives that have been tried. Rotation systems may fail because the rest periods are too short, too infrequent, or at the wrong season to allow forage plants to recover from grazing. The early spring period is especially critical for forage plants because cattle and wildlife, which are particularly hungry for nutritious green herbage at that time, regraze the fresh new growth on plants that have been previously grazed. Rotation schedules that intensify spring regrazing can weaken the favorite forage plants so severely that they are not able to recover during the ungrazed periods. Systems that have been successful rest each range unit from one-half to two-thirds of the time, and reduce spring regrazing by moving the herd to an ungrazed crop of old herbage for the spring period.

Average use of key forage plants under complex grazing systems should be about 40 percent—the same as for continuous grazing. If adequate rest periods are provided, however, the occasional heavy use in years of low forage production does not do serious damage. Animal weight gains often are slightly less for complex systems than for continuous grazing, probably because the animals are at times forced to graze more mature forage and because the additional moves disturb the animals.

The rest rotation system advocated by Hormay provides rest periods to meet specific requirements of the forage species: to recover vigor, promote seed production, and enhance new plant establishment. The system usually involves three or four pastures of about equal capacity. This system will benefit many semidesert ranges if the grazing schedules are properly meshed with forage growth periods.

The high-intensity/low-frequency system of grazing, which was introduced in Africa and is currently being tested in Texas, requires movement of all cattle from a pasture when the desired degree of forage use is obtained, regardless of season or forage phenology. The period of intervening rest is contingent upon the number of pastures and the level of stocking. Results to date indicate remarkable improvement in a few years where relatively long rest periods have alternated with short grazing periods.

On semidesert ranges in Arizona, rest for each range unit 2 years out of 3 during the period March through October holds promise for improving the range (table 2). Advantages reported under these systems include reduced labor costs because the cattle are in one pasture, and possibilities for range improvements such as brush control or seeding without fencing the treated area.

Unfortunately, climatic events can override the desirable effects of any grazing system in the semi-

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[4] *Suitable range is defined as range that can be grazed on a sustained-yield basis in harmony with other resource uses and values under reasonable management. Stocking rates that are cited apply to ranges classified as suitable.*

Table 2.--A grazing system being pilot tested on the Santa Rita Experimental Range that provides 12 months of rest immediately before each period of spring-summer (March-October) grazing

Season	Pasture 1	Pasture 2	Pasture 3
First:			
Spring-summer	Graze	Rest	Rest
Winter	Rest	Rest	Graze
Second:			
Spring-summer	Rest	Graze	Rest
Winter	Graze	Rest	Rest
Third:			
Spring-summer	Rest	Rest	Graze
Winter	Rest	Graze	Rest

desert Southwest. Severe and prolonged drought will reduce perennial grass stands whether or not they are grazed. Under these circumstances the range manager must reduce stocking to prevent undue range deterioration and animal losses. Range will recover more rapidly with favorable rainfall where the forage plants have not been overgrazed prior to the drought.

Range Improvement Practices

Practices aimed at increasing range productivity have been developed for semidesert grass-shrub ranges. All too often, however, the incentive to improve these ranges has been lacking because of their inherent relatively low productivity and high risk of failure unless proven seeding techniques are carefully followed. Range seeding, brush control, water spreading, rodent and rabbit control, and fertilization have been tried.

Seeding of semidesert grass-shrub rangelands may be needed and justified if satisfactory range condition cannot be restored within a reasonable time through grazing management or control of undesirable plants. Extreme scarcity of desirable plants is one of the most obvious indicators of the need to reseed. Suitability of the site for seeding, need for additional forage or ground cover, ability to protect and manage the seeded area, and costs and returns from seeding must be considered.

Reliable seeding methods are known for the better semidesert grass-shrub sites. Seeding generally should be done just prior to the summer rains. Fairly level areas with relatively deep, fertile, medium-textured soils will have the best chances for success. Seeding is hazardous where annual rainfall is less than 11 inches. Where annual rainfall is 11 to 14 inches, Lehmann lovegrass can be generally recommended for seeding depleted range sites. Sites above 4,000 feet that receive more than 14 inches of annual rainfall can be seeded to Boer lovegrass. On swale or bottomland sites a wider choice of species is available.

Site preparation is essential before seeding. If undesirable competing vegetation is abundant, it should be controlled before seeding. Measures to conserve moisture such as pitting with an eccentric disk, contour furrowing, and ripping have increased chances of seeding success. Broad, and shallow pits retain their value longer and produce more herbage. Larger seeds are best planted with a drill; a cultipacker-seeder should be used for planting small seeds.

In general, newly seeded stands should not be grazed until seed has been produced. By this time the root system has developed sufficiently so it will not be pulled out of the ground by grazing animals. Once seeded grasses are established, proper management of the stand is required.

The presence of one or more species of noxious plants decreases grass production and often accelerates sheet and gully erosion. Furthermore, the presence of overstory plants increases the cost of handling range livestock, a factor that is becoming increasingly important to the range livestock operator.

Mesquite is one of the most widespread overstory plants on Southwestern rangelands. It, together with woody species such as creosotebush, cacti, burroweed, and other noxious shrubs, has lowered materially the semidesert range forage productivity.

Control methods depend upon growth characteristics of the species, density, size, and whether seeding is required to achieve the desired range improvement. The method employed will also depend upon the site characteristics and management objectives for each area. Methods include hand grubbing, individual stem or stump treatments with diesel oil and/or herbicides, application of granular herbicides to the soil around trees, aerial applications of herbicides, individual tree dozing, cabling, roller chopping, root plowing, and prescribed burning.

For scattered mesquite, hand grubbing is effective for plants up to 1 inch in diameter. It is a high-cost labor method that will not pay immediate returns on the investment, however, because removal of small plants does not increase forage production perceptibly; it must be justified as preventive maintenance.

Immediate and often dramatic increases in forage production can be obtained by controlling moderate or dense stands of mesquite with herbicides or mechanical methods if there is a remnant of perennial grass. Treatments can be applied to individual trees or broad scale to a large area. Individual trees or groups of trees may be left for shade, esthetics, or wildlife habitat; however, remaining trees are centers for reinvasion.

Root plowing destroys or seriously disturbs all vegetation including perennial grasses, so reseeding at the time of plowing is usually mandatory for prompt reestablishment of a forage stand.

Fire was an important element in maintaining semidesert grasslands prior to white settlement. Although mesquites less than ½ inch in stem diameter are often killed, prescribed burning can rarely be used to control moderate to dense stands of large mesquite because there is seldom enough herbaceous fuel to carry a fire of sufficient intensity. Moreover, many perennial grass species may be severely damaged by fire and often are slow to recover.

The various control techniques mentioned above also can be used with some degree of success for other undesirable low-growing trees or shrubs.

Improving Livestock Distribution

Management practices applicable on most range ecosystems for improving livestock distribution include: stock water development, hauling of water, fencing for better livestock control, location and periodic movement of salt grounds, range riding, and construction of trails and driveways.

Livestock water can be developed by the use of windmills, deep-pit charcos, sand tanks, temporary ponds, horizontal wells, and paved runoff catchment areas with closed storage tanks. With flexible plastic pipe, water can be distributed from a central source to widely separated range units at a relatively low cost. Permanent waters should not be further than 4 to 5 miles apart in flat or undulating country, 3 miles in rolling country, and from 1 to 2 miles on rough ranges.

Fencing a range into suitably sized areas should be an integral part of the management plan of any range operation. Fence locations must be based on availability of water, topography and vegetation, class of livestock, and kind of grazing system used.

Salt placed away from water usually improves the distribution of cattle and increases forage use in lightly grazed areas. In rough terrain, salt grounds probably should not be over ½ to 1 mile apart, and location should be changed whenever the desirable forage plants show damage from trampling and grazing.

Riding to obtain better distribution of cattle is relatively expensive, but it is a positive method of dispersing the animals to achieve more uniform grazing.

As a companion to these management techniques, recommended livestock husbandry practices include gentle handling of animals, use of modern conveniences such as holding traps, corrals, squeeze and separating chutes, and branding tables. These greatly reduce animal losses and injuries as well as labor costs.

Additional Needed Guidelines

Sound informational guidelines have been developed for managing livestock production operations on semidesert grass-shrub ranges. The resource manager needs additional information, however, that will enable him to meet today's complex problems which encompass more than just livestock production.

In the semidesert Southwest, recent population increases of permanent and transient residents in large metropolitan centers and numerous scattered suburban communities have created a set of new challenges for the range manager. The economic advantages and the social demands which stem from this influx of people dictate that we now must develop knowledge that will enable the resource manager to integrate the various recreation and esthetic amenities which people expect to enjoy with the conventional and historical uses of the region.

Of particular importance is a provision for enjoyment of wildlife, both for its consumptive and nonconsumptive values. Wildlife habitat improvement is prerequisite to achieving this goal. Various grazing systems and range improvement practices must accommodate these new demands while at the same time, hopefully, increasing livestock production and improving the range. It will be the responsibility of the scientists representing several disciplines to determine acceptable tradeoffs for managing the semidesert grass-shrub ecosystem within a multiple use framework instead of for a single product.

Although we have a general understanding of the habitat types represented within the semidesert grass-shrub ecosystem, improved classification standards are needed as an adjunct to intensified management. With proper classification of the habitat types and knowledge of their potential, the manager will have available the basic building blocks.

If multiple use management is to be realized, we must develop improved methods of vegetation manipulation. Removal of mesquite or other taller vegetation in eye-pleasing and wildlife-benefiting patterns can increase the diversity of the ecosystem.

Since fire at one time was a component of prewhite settlement, better knowledge of its effects and how it can be used in the current management scheme could be important for the manager.

More intensive testing of forage and browse species, including methodologies necessary for their establishment, would be useful for rapid improvement of disturbed or deteriorated sites.

SOUTHWEST CHAPARRAL ECOSYSTEM

General Characteristics

Chaparral is a low and often dense scrub vegetation. In Arizona, the chaparral ecosystem occupies a relatively narrow band of broken, rough terrain below the Mogollon Rim. It extends through the central part of the State from northwest to southeast, at elevations mostly between 3,000 and 6,000 feet. Precipitation is concentrated in two distinct periods, summer and winter. In this, the Arizona chaparral ecosystem differs markedly from other chaparral communities of the world, whose climates are characterized by wet, mild winters and hot, dry summers. Annual precipitation averages from 15 to 25 inches; approximately half is received in the summer. Average snowfall within the type varies from 4 to 25 inches per year.

Settlement of the chaparral region lagged some years behind other range areas in the Southwest because of the rough topography. Cattle were brought in by settlers in the last quarter of the 19th century, and peak stocking was reached about 1900. Drought and overgrazing soon resulted in loss of carrying capacity and reduced livestock numbers. Originally the shrub cover was relatively open with excellent stands of interspersed grasses, but by the early 1900's the chaparral had taken on much of the dense shrub character evident today.

The present chaparral ecosystem is a remnant of a semiarid woodland and thorn scrub vegetation which once (pre-Pleistocene) extended from California to Oklahoma. With climatic changes and mountain building, the vegetation became separated into California and Southwestern segments. The chaparral type in Arizona is about all that remains of the Southwestern segment. According to Clements it represents a climax formation, but it is a climatic climax that is often subjected to huge conflagrations which temporarily destroy the shrub cover. Others have theorized that it is a fire climax which often presented a presettlement aspect of open grassland mixed with low shrubs that were suppressed by frequent fires and vigorous grasses. In either case, because the major shrub components either sprout prolifically after a fire or produce abundant seeds which are scarified by fire, chaparral stands tend to recover rapidly after burning with only minor changes in shrub cover.

The distribution of chaparral and adjacent intermingled vegetation types is complex. Chaparral is associated with pinyon-juniper, ponderosa pine, and desert ecosystems, depending upon combinations of environmental features and the ecological amplitudes of the characteristic species. Shrub crown cover is greater at the higher elevations, and decreases to about 25 percent at the lower elevations where it becomes transitional with the semidesert grass-shrub or desert shrub ecosystems.

Chaparral is found on soils developed from sedimentary, igneous, and metamorphic parent rocks. Sedimentary rocks predominate in the central portion of the type, however, and granitic rocks over most of the remainder. Soils are mostly sandy in texture, relatively shallow, and low in fertility. Lava and basalt substrates give rise to fine-textured soils, as do shales, sandstones, and limestones at higher elevations. The presence of shrubs on shallow soils usually indicates deep fracturing and weathering of the parent material.

Shrubs are more abundant on the coarser textured soils. On fine-textured soils, grasses are often dominant. Grazing favors the invasion of chaparral species, even on heavier soils.

Litter accumulates under the chaparral crown cover in significant amounts, and is important for protection of highly erodible soils on steep slopes. Accumulations in excess of 20 tons per acre have been reported.

At least 50 shrub species are reported in the chaparral type, although fewer than 15 are abundant. Most are low-growing, broad-leaved, evergreen, and either prolific sprouters or seed producers.

Shrub live oak is the most abundant species. At the lower elevations it is found with small amounts of other xeric components of the type, and also some of those of the desert shrub type. At the upper boundaries shrub live oak frequently extends as an understory into the fringes of the ponderosa pine or pinyon-juniper types. On representative areas, shrub live oak canopy cover may vary from 45 to 80 percent, with only one or two other shrub species contributing over 10 percent of the total shrub cover. It grows 3 to 8 feet tall in clumps, often with thousands of individual stems. Root crowns contain thousands of inactive buds which may sprout if the aboveground parts of the plants are killed.

Shrub live oak, because of its abundance and availability, may be an important emergency source of forage and cover for livestock and deer during winters of heavy snow. New succulent growth i readily grazed, but older growth is low in palatability. The acorns are relished by deer, turkey, and possibly other mammals and birds.

Two species of cercocarpus, hairy and birchleaf are important browse species for livestock and dee in the chaparral. These shrubs seldom form pur stands, but may dominate localized areas. The sprout from root crowns following fire, but repeate burning diminishes their capacity to sprout.

Desert ceanothus occurs throughout the chaparral type, but is more common at the lower elevations. It seldom exceeds 6 feet in height and is relatively short lived. Although not as palatable for cattle as some other species, it has been rated excellent as a food for deer.

Pointleaf and Pringle manzanitas are common in the Arizona chaparral. They often are found in large clumps which may form impenetrable thickets several hundred acres in extent. Although these species seldom sprout, they readily reproduce from seeds and by layering. Seeds are scarified by fire, and great numbers of seedlings quickly reoccupy burned areas. Manzanitas are relatively long lived and have no forage value for most herbivores.

Skunkbush sumac is common throughout the chaparral type, but seldom contributes more than a few percent to the overstory. Fire-damaged plants sprout vigorously from the root crown. It is very low in palatability and nutritive value for most livestock and deer, but is reported to be highly palatable to goats.

Other frequent shrub species in the chaparral include hollyleaf buckthorn, Wright silktassel, cliffrose, sugar sumac, catclaw mimosa, and Emory oak. Most of these are prolific sprouters, particularly after fire, and occur in varying amounts throughout the chaparral type. Young sprouts of these species are browsed by livestock and wildlife to some degree, depending upon their abundance and that of other plants.

Much of the chaparral type is now in poor range condition. The shrub cover has increased, with corresponding decreases in the herbaceous understory. Perennial grasses which were at one time more abundant include gramas, dropseeds, threeawns, curlymesquite, bluestems, and Texas timothy. Guides developed for evaluating range condition of Arizona chaparral ranges are based on the relative abundance and productivity of desirable perennial grasses in the openings between shrubs. Additional factors considered include the density of the shrub stand, presence and degree of hedging of palatable shrubs, evidence of active erosion, and other indicators of heavy grazing.

Range Management Prescriptions

Stocking and Forage Use

Stocking rates on chaparral range must be carefully adjusted to the available forage because of the strong competitive effects of shrubs on interspersed forage grasses. If not more than 40 percent of the perennial grass production is utilized, the grasses can usually maintain themselves in a vigorous condition and provide adequate soil protection. The use of most browse species should not exceed 30 to 35 percent of the current year's twig growth.

Chaparral ranges in good condition have a grazing capacity of 5 to 15 acres per cow month or about 4 to 11 head per section yearlong. Where a combination of animals such as cattle and goats are grazed on the same chaparral range to better utilize the shrubby and herbaceous components, their numbers must be balanced with the available amounts of preferred forage for each animal. Management techniques suitable for such multiple use can be developed to increase the income compared to that from a single class of livestock. For example, goats would be a means for controlling sprout growth where fire or herbicides had been applied, and thereby encourage grass growth for cattle use.

The nutritional quality of a chaparral range is complex because of the diversity of herbaceous and woody forage. The nutritive content varies among species of plants, plant parts, and seasons of the year. Nutritive analyses and digestibility trials have been made on deer forages in the chaparral, but not for domestic livestock.

Grazing Systems

Although most chaparral ranges are grazed yearlong, some are used only for fall-winter-spring grazing. They are particularly well suited to yearlong use because of the different growth patterns of shrubs and grasses: most shrub growth occurs in spring at which time they are more palatable, whereas most grass growth takes place later as a result of summer rains. Observations indicate that both classes of vegetation would benefit from a more intensive system of grazing, but this aspect of range research has been limited in Arizona chaparral.

Summer deferment every other year on deteriorated ranges and once every 3 to 5 years on chaparral ranges in excellent condition has been recommended. A four-pasture grazing system has worked well for an operating ranch in the chaparral type west of Prescott. All cattle are kept in one pasture. Use on the four pastures is rotated so that no pasture is grazed more than half of any one growing season or the same season in any 2 successive years. Benefits of the plan after 2 years were reported as: (1) ease of looking after the cattle in a single pasture, (2) increased vigor of perennial grasses, (3) perennial grass establishment near stock water and in gullies, and (4) more even utilization.

Range Improvement Practices

Controlling undesirable shrubs coupled with seeding of various forage species may greatly increase livestock production on some chaparral ranges (fig. 2). Furthermore, replacement or disruption of the dense shrub cover substantially increases water, reduces fire hazard, and improves access for recreation. Wildlife habitat can also be improved if the shrub-controlled area is not too large.

Numerous methods of shrub control have been tested under a variety of conditions: mechanical (cabling, chaining, railing, root plowing, bulldozing), burning, chemical, biological, and various combinations of these. Root plowing is the most effective mechanical method, but only 2 to 8 percent of the chaparral type can be safely root plowed, because of large rocks, gullies, and steep slopes. The heavy blade pulled by a tractor at a depth of from 8 to 18 inches in the soil—just below the shrub root crown—severs the crown and lifts the plants out of the ground. If properly done, more than 90 percent of the shrubs may be killed.

Herbicidal control of chaparral has been concentrated on shrub live oak, because it is the dominant species in the type and is very difficult to kill. Even with repeated annual applications that kill the aerial portions of the plant, it continues to sprout from the root crown. Picloram and fenuron appear to offer more promise for control of shrub live oak and other resistant species than the phenoxy herbicides, 2,4,5-T and silvex. Picloram and fenuron have been applied as soil drenches and also as foliage sprays. Hand application of pelleted fenuron under shrubs and trees also provides effective control and results in increased vigor of native grasses and forbs in the inter-shrub spaces. Differential susceptibility of major chaparral species to picloram and fenuron provides numerous possibilities for manipulating chaparral cover by favoring or controlling specific species.

Fire alone produces only a temporary beneficial effect, because sprouting shrubs regain their former cover in only a few years. Burning, followed by seeding of grasses and sprout suppression with chemicals, holds more promise. Many chaparral areas

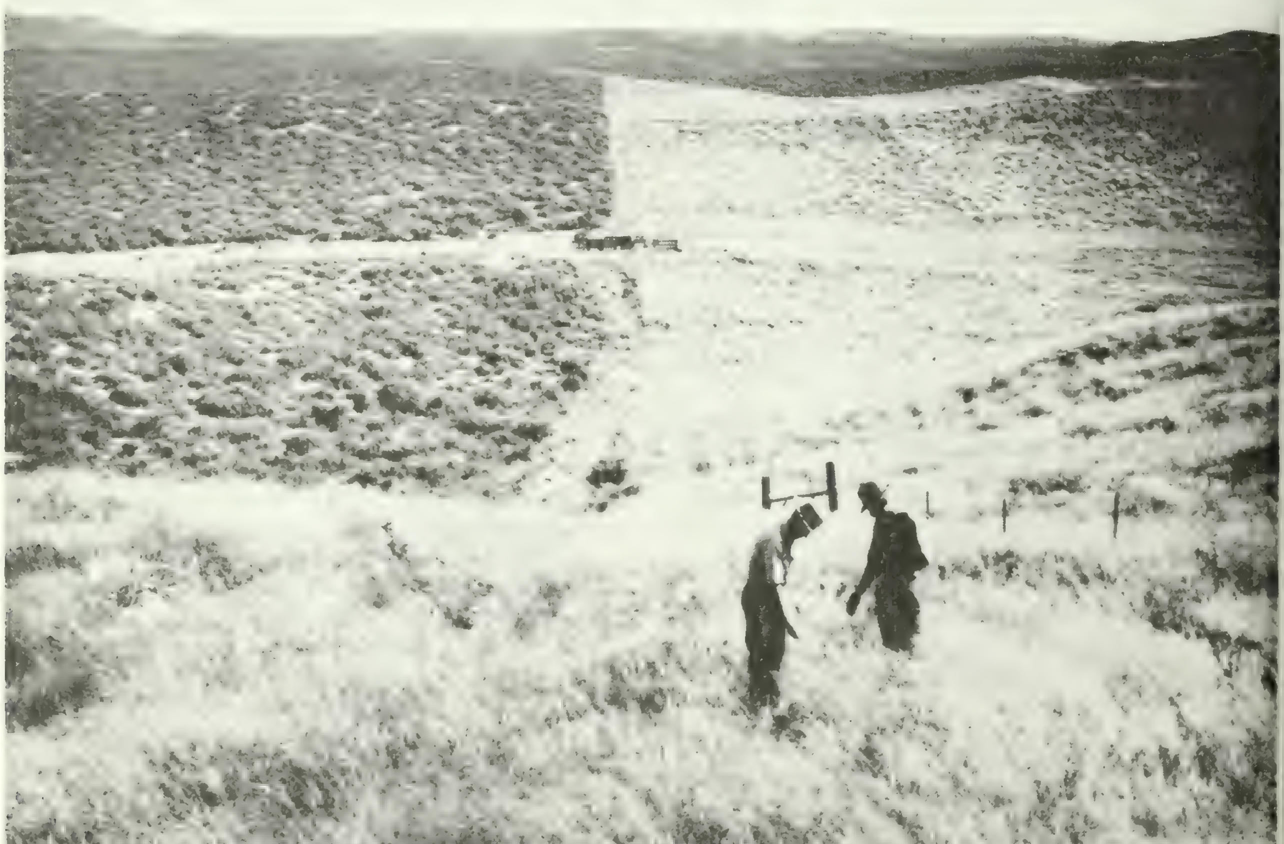

Figure 2.—Elimination of chaparral (mainly shrub live oak) and seeding to grass (weeping lovegrass) can increase beef production as much as tenfold.

that have been burned and then seeded can produce large amounts of perennial grass forage if sprouting shrubs can be held to less than 5 to 10 percent crown cover.

Prescriptions for planned broadcast burning of shrubs with minimum damage to the herbaceous understory and soil require that burning be done in the fall. Specifications for successful chaparral burns are: (1) vegetation must be dormant or nearly so, and (2) optimum conditions of relative humidity range from 14 to 35 percent, fuel moisture from 8 to 18 percent, and wind not over 4 miles per hour. Burning can be successful under less than optimum conditions by pretreating the vegetation with chemical desiccants. Drying the foliage improves topkills, and also permits burning at seasons when risk of escape and damage to understory herbaceous plants is much less.

Other combinations of shrub control treatments are possible, such as mechanical-chemical treatments employing root plowing and followup spot chemical applications to control sprouts, and burning followed by placing goats on the area to browse the sprout growth. Some combination of treatments can be applied on most areas of the chaparral type regardless of topography and, in general, will produce better results than single treatments.

Seeding of native or introduced forage species in conjunction with shrub reduction is mandatory in most situations for improving condition of chaparral ranges. Seeding recommendations for the chaparral type recognize three precipitation zones and upland and bottomland sites. Recommended species include 2 legumes and 14 grasses. Recommendations for improving seeding success include selection of relatively level sites with rather deep, rock-free soils; preparation of a suitable seedbed, including removal of competing vegetation; planting of seed at a proper depth and compacting the soil over the seed (broadcasting may be feasible with small seeds); and finally, subsequent proper management of the stand once it has been established.

Where seeding has been successful, herbage production has exceeded 2 tons per acre in some cases; an increase of 1 ton per acre is common. Grass production may be expected to reach a maximum in the second or third year after seeding, followed by a decline of one-half or more from the maximum production depending upon subsequent shrub recovery. In one grazing study, 40 pounds of beef per acre per year were produced on a converted chaparral range seeded to lovegrass compared to 10.8 pounds of beef per acre on native chaparral ranges.

Range fertilization has had very little testing. It may be beneficial on some chaparral sites, but the frequent deficiency of summer precipitation considerably limits the chances for success on Arizona rangeland.

Fencing, salting, riding, and trails are accepted means of achieving better livestock distribution in the chaparral type, as they are on most range types.

Water development has increased with more intensive management and shrub conversion in the chaparral. Improved springs, windmills, horizontal wells, and earth tanks are being developed. In some cases following conversion, previously intermittent streams have become permanent, thereby creating additional water sources.

The chaparral ecosystem does not now contribute materially to water yield in Arizona, but increases following conversion of chaparral to grass approach those of pine-fir and mixed conifer sites. The large increases presumably result from reduced transpiration when deep-rooted shrubs are replaced by shallow-rooted grasses and forbs that use less water.

The chaparral yields water largely during the winter and spring. The increased water following conversion of an area to grass follows the same pattern, so that most of the increase can be expected to reach a point of use downstream.

Deer populations are relatively low where the brush is dense and herbaceous understory is sparse. Livestock and wildlife both benefit from opening up chaparral. The optimum size of opening for deer is much smaller than for cattle. The production of young, nutritious sprouts, especially if treatments were designed for periodic renewal of sprout production, would definitely provide more browse for both livestock and deer.

At present, the chaparral receives relatively little use by hunters and recreationists because of its inaccessibility. Conversion of selected areas to grass would greatly increase diversity of the ecosystem, and use by hunters and picnickers.

Additional Needed Guidelines

Use and management of the chaparral present difficult problems. Limited research and pilot trials involving conversions of chaparral to grass show we are making inefficient use of the resource. Forage production and other benefits can be increased by more effective and economical treatments designed to: (1) convert chaparral to grass or otherwise open up the chaparral stand, (2) maintain the shrub component in a new-sprout rather than a mature state, or (3) modify the shrub composition to increase the more palatable plants and decrease the unpalatable ones.

The technical information needed to fully realize the potential of the chaparral ecosystem includes: (1) refinement of techniques for prescribed burning to topkill the shrubs with minimum damage to the interspersed perennial grasses, (2) better mechanical methods of shrub control that can be applied on most soil types and slope conditions, (3) methods to control or otherwise manipulate subsequent sprout development, (4) development of more highly selective chemicals for individual species control, and (5) techniques for establishing desirable shrubs, and more effective seeding methods.

Other problems which still stifle intensive management include: (1) how to measure shrub production, (2) tolerable levels of shrub use, and (3) optimum scheduling of use and rest for sustained grass and shrub production. Also, grazing systems are needed that take advantage of the peculiar growth requirements of the herbaceous and shrubby components, and incorporate dual use of an area by cattle and goats. The latter animals may be included in the management as a treatment mechanism which, if properly applied and managed, may materially decrease the costs of maintaining a chaparral conversion and increase the returns from the operation.

Proximity of the chaparral ecosystem to the expanding Phoenix metropolitan area will probably lead to marked shifts in priorities for the land resources. Water will continue to be a major economic product where there is opportunity for conversion of chaparral to grass, but demands for amenity values associated with urbanization also can be expected to increase in such nonconsumptive activities as hiking, photography, and picnicking. Enhancement of these attributes within the chaparral ecosystem will require sound research information.

General Characteristics

The pinyon-juniper woodland or dwarf conifer ecosystem is characterized by a shrubby tree overstory of one or more species of pinyon pines and junipers. The most common pine is pinyon, sometimes called Colorado pinyon, but Mexican pinyon is found in the southern portions of the area and single-leaf pinyon in northwestern Arizona (Little 1971). Rocky Mountain juniper is found in all States of the central and southern Rocky Mountains, but is most common in Colorado and Wyoming; one-seed juniper is an associated species in Arizona, New Mexico, and south-central Colorado. Utah juniper is common in Arizona and western Colorado. At the higher elevations, alligator juniper may be found along the Mogollon Rim in central Arizona and in the Gila and Sacramento Mountains in New Mexico.

The pinyon-juniper type generally is found from 4,500 to 7,500 feet elevation; it has been reported at 9,000 feet on the San Augustin Plains in New Mexico. At its upper limits it intergrades with Gambel oak and ponderosa pine, and at its lower limits with semidesert grass, short-grass, chaparral, or desert-shrub types.

Tree density varies from scattered individuals to several hundred stems per acre. There is usually very little understory in the latter situation. Pinyon is often more abundant than junipers at the higher elevations and in northern New Mexico and southern Colorado. Throughout most of the type, however, junipers outnumber pinyons.

Blue grama is the most abundant and frequent understory species, but other common ones include several gramas, western wheatgrass, galleta, squirreltail, Junegrass, muttongrass, Indian ricegrass, sand dropseed, eriogonum, and rough menodora. Associated shrubs are often rabbitbrush, big sagebrush, snakeweed, antelope bitterbrush, cercocarpus, cliffrose, ceanothus, and serviceberry.

Annual precipitation for the ecosystem averages from 12 to 18 inches and may reach 20 inches on some sites. Seasonal distribution is similar to that in the semidesert grass-shrub type; in eastern New Mexico, 75 percent falls during the growing season, April through September, compared to only 45 percent in western Arizona. In western Colorado about half of the 12 to 15 inches of precipitation falls in this period. Also, growing-season precipitation becomes more concentrated in the period July to September from east to west, and very little spring moisture is received. This summer monsoon pattern becomes less pronounced in northern Arizona where much of the precipitation comes from cold winter storms, and the vegetation shows affinities for the Great Basin region. In contrast, in eastern New Mexico the vegetation forms broad ecotones between pinyon-juniper woodland and Great Plains grassland.

Snow is rarely deep in the pinyon-juniper ecosystem except at the higher elevations, and usually melts in a few days, especially on south-facing slopes.

The ecosystem is found on a wide variety of soils derived from granite, basalt, limestone, and mixed alluvium parent materials. Soils vary in texture and depth, and site quality is a function mainly of depth, profile development, and precipitation.

Prior to widespread settlement of the Southwest, pinyon-juniper stands were more open and confined largely to the rocky ridges or more level sites with shallow soils. As elsewhere in the West, the great influx of domestic livestock in the late 1800's soon depleted many ranges, and forage species afforded little or no competition to tree seedlings. Due to the combination of overgrazing, absence of fires, and dissemination of seeds by mammals and birds, trees have encroached on the grasslands and original stands have become more dense.

The understory herbaceous vegetation varies according to grazing history, density of the trees, and the physical features of the site (fig. 3). Spring grazing has been particularly detrimental to cool-season grasses such as muttongrass, bottlebrush squirreltail, and western wheatgrass. These species have already disappeared from the plant community in many areas. Perennial grasses and forbs decrease in proportion to the increase in tree overstory. The effect of tree overstory on shrubs becomes pronounced when the tree canopy exceeds about 60 percent. Suppression of understory appears to be related to tree litter and root competition. The tree roots provide more competition to the lesser vegetation in the openings than directly under the tree crowns. Suppression of understory by juniper trees is most pronounced on heavy clay soils. Foliage extract of juniper also has been shown to decrease germination of gramas.

A dense tree canopy may preclude any significant changes in understory, even under protection from grazing. Where the tree cover is not too dense, midgrasses generally increase where there is protection from grazing.

Fire has been a natural ecological factor that slowed the invasion of juniper and pinyon, and converted stands of old trees to grasslands. After fire, succession begins with the establishment of annuals which reach peak production in the second and third year. Perennial grasses and half-shrubs then become prominent, followed by either a perennial shrub stage with species such as sagebrush or rabbitbrush,

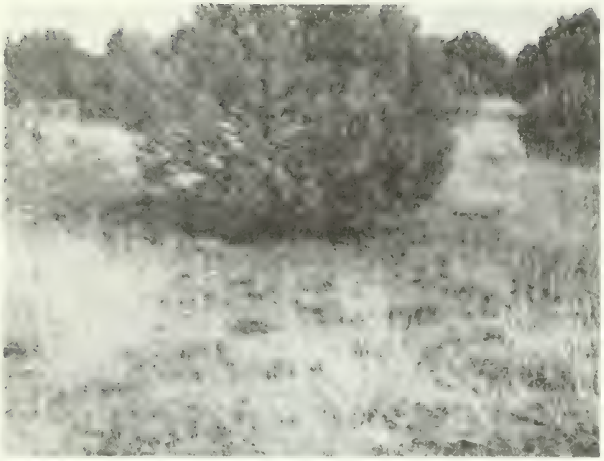

Figure 3.—Pinyon-juniper woodland, the most extensive of the seven range ecosystems, may have a good stand of forage species as an understory unless the trees are too dense or grazing has been severe.

or a perennial forb-grass stage. Without recurring fires, the shrub and perennial grass stages eventually will be replaced by climax pinyon-juniper.

Pinyon-juniper ranges have been grazed by livestock for well over 200 years. Grazing continues to be an important use, and the type provides valuable wildlife habitat. Tree products are mainly firewood, charcoal, Christmas trees, and fenceposts. Harvesting of pinyon nuts sometimes provides income and recreational opportunities to local residents. Now recreational pressures, housing developments, roads, and related activities are creating serious problems in the ecosystem.

Cow-calf operations predominate in the pinyon-juniper type. Calves are dropped in the spring and marketed in the fall. Yearling operations are more common where the rancher is dependent on non-public leased grazing lands for a large portion of his annual forage requirement. Since World War II few woodland ranges have been grazed by sheep although there are opportunities for common or dual use by sheep and cattle particularly where there are numerous forbs and shrubs.

Ranch operations which depend entirely or in part on forage in the pinyon-juniper ecosystem vary in size regionally. In northern New Mexico, operations are often small in contrast to those in other areas which may often graze several hundred cattle.

Range Management Prescriptions

Stocking and Forage Use

Most pinyon-juniper ranges historically have been grazed yearlong. However, some are used only during specific seasons. Yearlong use is more prevalent in the southern part of the ecosystem; winter climate necessitates seasonal use in the more northern portions. To supplement their native forage supplies, some ranches have irrigated or improved pastures while other depend upon concentrates and roughages.

Grazing capacity of the pinyon-juniper type varies considerably with tree density, topography, range condition, and other factors. Many pinyon-juniper ranges are in only fair or poor range condition as a result of prolonged overgrazing. Most range managers consider use of the forage grasses in excess of 40 percent to be detrimental to the plant. Guidelines for woodland ranges suggest leaving one-third of the culms ungrazed at the end of the season. Average grazing capacity in the Southwest varies from 4 acres per animal unit month (AUM) on ranges in good condition to 28 acres per AUM on those in very poor condition. Differences also reflect the variable plant communities and environmental conditions over the broad geographic range of the ecosystem.

Grazing Systems

Increasingly large acreages of pinyon-juniper rangeland in public and private ownership are being more intensively managed under grazing systems other than yearlong or seasonlong. On National Forest woodland ranges in the Southwest, more than half of the allotments now are under some form of rotation, deferred, or deferred-rotation grazing; rest-rotation, which provides for at least a full year of rest for a unit, is a fairly common system. The intent is to enable the forage species to recover from the effects of herbage removal and provide for food storage, recovery of vigor, seed ripening, seedling establishment, and litter accumulation. Guidelines for summer grazing systems on woodland ranges should include resting poor condition range every summer, fair condition range every other summer, and good condition range once in 3 years.

Success of any grazing system depends on favorable moisture conditions. Although droughts are somewhat less severe and less prevalent than in the semidesert grass-shrub ecosystem, a lack of precipitation at the right times may negate what would otherwise be a successful grazing system. Forage plants will recover more rapidly from drought where provision has been made for meeting their growth requirements prior to the drought.

Range Improvement Practices

Many pinyon-juniper ranges support more livestock if improved by plant control, seeding, fertilization, and proper management. Range seeding in the pinyon-juniper type has been successful when site selection, removal of overstory competition, seedbed preparation, selection of species to seed, and planting techniques are carefully considered. With successful seeding and subsequent proper grazing management, the additional forage supplies may well be the margin needed for the rancher to continue in business.

In some cases seeding may not be necessary if an adequate cover of native forage plants persists on the area and the overstory competition is removed. The tree overstory can be controlled by a variety of methods, from hand chopping, sawing, or grubbing to techniques utilizing various types of heavy equipment. Hand methods are practical for scattered trees on a small area, or as a cleanup in conjunction with more highly mechanized methods. Costs are high, although hand methods are considered to be the most thorough.

A crawler-type tractor fitted with various types of specialized equipment is effective for tree removal where stands do not exceed 100 trees per acre, or where tree cover is less than 10 percent. Single trees are removed by pushing them over or uprooting them with a modified bulldozer blade.

A tree crusher is particularly effective in dense stands of trees. The debris left as the crusher moves through the stand is in relatively close contact with the ground and therefore decomposes rather quickly. The debris is of a size that can be utilized readily by local residents for firewood. Tree crushing is especially suited to large areas (1) with a remnant stand of grasses and forbs that have the capacity to respond to removal of the tree competition, and (2) where esthetics is an important consideration. Crushing is limited to areas having nonstony soils and slopes of less than 15 percent.

Dragging a heavy anchor chain or cable between two crawler tractors has been used to clear many dense pinyon-juniper stands. Chaining is generally more effective than cabling. Double chaining in opposite directions is most effective for removing a high percentage of large trees and many smaller ones, especially in medium to dense stands. The method is relatively inexpensive, but regrowth and release of younger trees which the chain slides over may present a formidable followup problem. These younger trees may be harder and more expensive to treat than the original stand. Chaining followed by windrowing the debris, though most costly, is usually more effective.

Controlled burning should be considered a feasible pinyon-juniper conversion technique where vegetation is dense enough to carry a fire. Fire may be used in (1) broadcast burning, (2) killing trees invading grasslands, (3) burning individual trees, and (4) burning slash where trees were initially treated by another technique.

Dense, mature stands of pinyon-juniper can be broadcast burned during hot, dry, windy weather. The situation is hazardous and the standing dead trees are unattractive, but numerous examples show the effectiveness of such prescribed burning. Broadcast burning to control small invading trees has been tried on a limited scale. In these cases grazing must be deferred for a growing season so that enough fuel accumulates to carry the fire. Protection from grazing also is desirable for a growing season following the burn.

Individual tree burning is best suited to open stands, especially with small trees of one-seed or Utah juniper. The method is not appropriate for trees more than 10 feet tall nor for sprouting species. An advantage is that individual trees can be burned at any season.

Chemicals have not been used widely for control of pinyon or juniper trees. The chemical method is best suited to light infestations or as a followup to mechanical control where treatments can be applied to individual trees. Table 3 describes and points out the limitations of the several methods.

The range may be seeded during chaining or similar operations that sufficiently disturb the soil and provide a seedbed of mineral soil. Seed can be broadcast with a mechanized seeder and covered with a harrow, chain, or similar equipment. On large projects where areas are double chained, seed is commonly broadcast aerially between the first and second chaining.

Where trees are removed by pushing or uprooting, seed may be broadcast by hand in a followup operation. Often, seed is distributed in the pits where trees have been removed or on areas where mineral soil is exposed and disturbed.

Where the land has been cleared of debris from the control operation, seed can be drilled to increase chances of successful establishment. Although costly, plowing is most effective where it can be used for seedbed preparation and eliminating undesirable competing understory vegetation.

Other cultural practices that concentrate and conserve soil moisture usually increase the success of seeding pinyon-juniper ranges. Several mulches have proved effective, including tree branches, dead herbaceous material, plastic film, petroleum resin, and asphalt.

In northern New Mexico and Arizona, crested wheatgrass is often recommended for seeding in the pinyon-juniper type, especially where big sagebrush was the principal shrubby understory species. Weeping lovegrass is well adapted in eastern and central Arizona and areas below the Mogollon Rim where summer rainfall is high and winter temperatures mild. Other adapted species include western wheat-

Table 3.--Methods of pinyon-juniper control (extracted from Range Improvement Handbook prepared by Southwestern Region (R-3), USDA Forest Service 1970)

Method and type of equipment	Time	Limited to	Remarks
TREE CRUSHING Modified tree crusher.	Use when ground is not frozen or when excessive moisture is not present.	Large acreages of nonstony soils on slopes of less than 15 percent. Optimum benefit-cost ratio in very dense stands.	Gives good results with esthetic values.
BURNING Propane torches; fire control equipment.	Spring or summer.	Light infestations of small trees for individual tree burning. Optimum benefit-cost ratio with light stands.	Gives good results, and warrants wider use. May be used following chaining.
CHAINING (CABLING) Chain weighing 70 pounds or more per link.	Any time except when ground is frozen.	Large acreages of mature, even-aged trees. Optimum benefit-cost ratio with light and medium stands.	Fire for debris cleanup must be part of the treatment.
CHOPPING Brush chopper.	When seeding is needed, coincide with seeding time.	Little trees in small, odd-shaped areas.	Limited application; gives fair results. Poor results on alligator juniper.
ROTOCUTTER Highway-type mower. Heavy duty rotary mower.	Treat when least damaging to associated species.	Areas with small trees and no stones.	Gives good results. Will not kill alligator juniper. Desirable treatment for new invasion.
PUSHING (DOZING) Wheel or track-type tractor with blade or "stinger."	All year. Do not push alligator juniper when ground is frozen.	Light and medium stands.	Burning, windrowing, or stacking debris where necessary should be a planned part of the treatment.
HAND GRUBBING Grubbing hoe.	All year except when frozen.	Light and medium infestations of small trees.	Gives good results. Use as followup treatment or on new invasion.
HAND CUTTING Ax or saw.	All year.	Light infestations.	Gives good results except on alligator juniper, where it is ineffective. Wood products may return part of cost.
CHEMICAL SOIL STERILANT Fenuron-- *Rate*: Trees less than 6 ft high, 1 T. on light and medium soils; 2 T. on heavy soils. Double amounts for trees 6-12 ft high.	July to September.	Light stands only.	For other chemical treatment, see Section in Handbook on *Chemical Control of Range Woods*.
CHEMICAL STUMP TREATMENT Ammate crystals; or 2,4-D and 2,4,5-T with diesel; or Benzae 94.	At time of cutting.	Light stands only.	Alligator juniper only.

grass, Russian wildrye, sideoats and blue gramas, sand dropseed, spike muhly, Turkestan bluestem, yellow sweetclover, and fourwing saltbush. On good sites in western Colorado which receive more than 12 inches precipitation, the following species have shown promise: wheatgrasses (Fairway, crested, stiffhair, pubescent, Siberian, and intermediate), Russian wildrye, Indian ricegrass, squirreltail, smooth brome, needlegrasses (subalpine, needle-and-thread, and green), some alfalfa varieties, and Siberian pea.

Limited fertilization tests have shown herbage production can be increased sufficiently to warrant doubling the stocking rate. Forty pounds of available nitrogen per acre applied for 3 years increased the gains of heifers from 23 to 48 pounds per acre per year.

Range improvement practices should be coordinated with wildlife habitat requirements by (1) not clearing slopes steeper than 15 percent, (2) leaving existing cover on northeast exposures, and (3) removing or thinning trees where they exceed 150 per acre on areas reserved for wildlife. Cleared areas should have a maximum edge effect so that deer using the created openings are never far from cover. Ideally, the openings should be not more than ¼ mile wide.

The control method chosen should cause minimum damage to browse plants on ranges important for wildlife. Burning of dense woodland on certain areas with fairly rough terrain may be an acceptable practice if sprout growth can be stimulated for the benefit of deer and antelope.

Managers should strive to maintain the cercocarpus and oak found in the pinyon-juniper type, because they contribute to deer nutrition. Habitat for desert cottontails and possibly other small animals can be enhanced by leaving down, dead trees scattered through the control area.

Opportunities for increasing water yields through manipulation of pinyon-juniper stands do not appear promising. A water yield increase of 0.45 inch (65 percent) was obtained in a single experiment in Arizona with the aerial application of a mixture of picloram and 2,4-D. Chemical conversion treatments to increase water yields cannot yet be recommended, however. The only realistic management practice for conversion is by mechanical treatments, which have not increased water yields. Clearing juniper increases water available for producing forage, but soil water storage capacity in the upper 24 inches is seldom exceeded in northern Arizona.

Additional Needed Guidelines

Present information enables the land manager to maintain the status quo for many pinyon-juniper ranges where deterioration has not progressed too far. However, additional knowledge will be required to more fully realize the potentials for improvement and multiple use outputs that exist for this extensive ecosystem. The resource manager could effectively use better environmental classifications and more accurate maps which recognize the diversity of soils, climate, and vegetation within the ecosystem. Planning must be within a holistic framework that includes more than domestic livestock considerations. Recognition of scenic values, wildlife habitat, recreation, and minimization of soil losses must be included. Demands for home sites and the attendant requirements for road construction, waste disposal, and water development plus the usual recreation-related problems must be met. Few definitive guidelines based upon sound multidisciplinary research are available to meet these needs.

CENTRAL ROCKIES PONDEROSA PINE-BUNCHGRASS ECOSYSTEM

General Characteristics

The ponderosa pine-bunchgrass ecosystem of the central Rocky Mountains occurs in a zone 5 to 25 miles wide through a change in latitude of 400 miles from New Mexico to Wyoming. The forest is found on both sides of the Continental Divide at elevations of 5,000 to 9,500 feet.

Annual precipitation varies with elevation, latitude, and longitude. West of the Continental Divide it averages from 14 to 18 inches, of which approximately 50 percent falls as snow. Through the Front Range portion of the ecosystem east of the Continental Divide, about two-thirds of the precipitation occurs in the April-to-September growing season. Annual precipitation varies from about 15 inches in the southern portion to over 25 inches in Wyoming. (fig. 4). Exposure and the base geology exert a profound influence on the vegetation and soils. North of the Arkansas River the parent materials are primarily granite with occasional extrusions of other materials. To the south, schist, gneiss, and sedimentary sandstones and shales predominate.

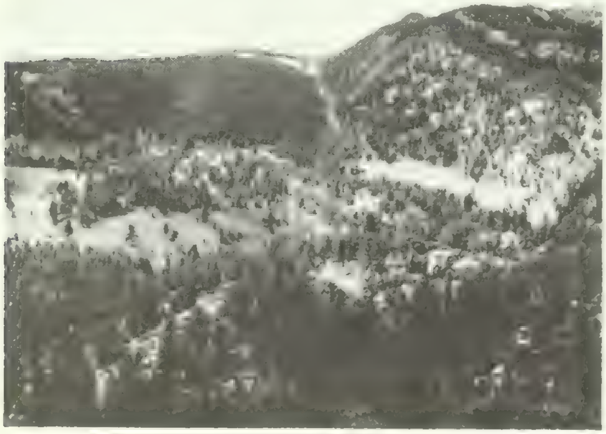

Figure 4.—The ponderosa pine-bunchgrass ecosystem of the central Rockies is often characterized by broken, rough topography. It furnishes forage for livestock and wildlife under the open tree canopy and in interspersed grassland parks.

Soils developed from schist have a fine, sandy loam surface soil and may be up to 20 inches deep. Subsoils are usually absent, and water penetration may be facilitated by deep weathering of the parent rock. Soils derived from granitic parent materials are extensive and range in depth up to 10 inches, usually as gravelly or coarse sandy loams. They tend to be less fertile and more erosive than other soils of the ecosystem. Shale-derived soils are usually fertile but subject to excessive sheet erosion when protective plant cover is absent. Surface soils may be up to 18 inches thick, usually with a clay to clay loam texture.

The ecosystem includes grassland parks, stringer meadows, open stands of timber with a herbaceous understory, and extremely dense stands of ponderosa pine where there is little more than a mat of needles and small twigs on the ground. In the southern and western portions of the region, oak brush occupies cutover pine sites, and in many places is of sufficient density and permanence to be classified as a distinct type.

Herbaceous communities in the pine type are often considered transitional to the ultimate climax pine forest. Certain herbaceous species appear in the later seral stages and are also characteristic understory components of the mature forest.

Generally, the Arizona fescue-mountain muhly herbaceous community is prominent in the forest understory in the southern two-thirds of the zone. As many as 35 species of grasses are present where ponderosa pine-bunchgrass ranges are in good to excellent condition. Forbs may be numerous, but fluctuate from year to year, and only a few species are abundant enough to warrant consideration. Idaho fescue replaces Arizona fescue in the northern part and upper limits of the pine zone. Thurber fescue and Idaho fescue may replace Arizona fescue in western Colorado and northern New Mexico.

Livestock grazing became important between 1880-90. By the mid-1930's, however, animal months of grazing began to decline on National Forest lands. Long-overdue recognition of the adverse effects of mismanagement on watersheds was an important factor leading to reduction in grazing.

Most of the ponderosa pine-bunchgrass lands may be used for timber production, grazing, and recreation without adversely affecting their watershed protective values. The forests are an important summer and sometimes yearlong habitat for a number of wildlife species, which can be managed in connection with timber production and cattle grazing. Where suburban recreation activities have supplanted these conventional uses, other wildlife can often be favored by application of additional habitat management practices.

Sizable acreages of the ecosystem are in private ownership, especially along streams and other productive or scenic sites. Grazing has often been severe, and corrective measures slow in emerging on many private holdings. In recent years, ranchers and public land managers have been reseeding, fertilizing, and employing various systems of grazing to maintain and improve their ranges. On many private ands occupying the most accessible and esthetically desirable sites, uses other than grazing are assuming greater importance. Water will continue to be a primary resource, influencing all land-use activities.

Range Management Prescriptions

Stocking and Forage Use

Cattle grazing is seasonal on most ponderosa pine-bunchgrass ranges of the central Rockies. Grazing may be either continuous from late spring to late fall, or restricted to shorter periods by dividing the area nto a number of units and moving the livestock among them during the grazing season.

Utilization of 30 to 40 percent of the current annual growth of the major forage grasses provides maximum sustained production of both forage and beef on ponderosa pine-bunchgrass ranges. Lighter rates reduce total livestock production, although ndividual animal weight gains are greater. Grazing the major grasses in excess of 40 percent will damage the range and eventually lower livestock production.

Most livestock graze in the open grassland parks within the ponderosa pine-bunchgrass ecosystem. Some use is made of the open timber type, but cattle seldom graze within dense timber where forage is sparse. From 2 to 3 acres per animal unit month to as many as 8 to 15 acres/AUM are required depend-ng on slope, range condition, and the combination of associated cover types. About 10 acres/AUM are required where cows and calves are grazed on range n fair condition.

The forage is usually ready for grazing between June 1 and 15, and may be grazed as late as November. Animals seldom gain weight after September, however, on native bunchgrass herbage. Neverthe- ess, crude protein and phosphorus content of native forage in the ponderosa pine type appear to be at east adequate for grazing animals 8 months of the year.

A range with a large percentage of the forage comprised of Arizona fescue, sedges, or little bluestem would best be used early because of seasonal development of forage. Ranges that have a predominance of mountain muhly are more suitable for mid- to late-season grazing, when this species reaches its maximum production.

Grazing Systems

Bunchgrasses provide much of the forage. Since they reproduce from seed, management should try to encourage reproduction of desirable species. As on other ecosystems, cattle graze the range selectively, consistently eating certain plants on certain areas more than others. The manager can attempt to disrupt or alter this pattern to obtain more use of all plants present. While seasonlong or continuous grazing is common, some form of rotation and/or deferred grazing is also used. This includes variations of the rest-rotation system proposed by Hormay and Talbot (1961), which was developed on a pine-bunchgrass range in California.

Some stockmen have voiced concern that frequent livestock movements or changes in the available forage gives lower cattle weights than where animals graze an area seasonlong. Systems of management that recognize the physiological requirements of the forage species usually benefit the range. The synergistic effect of better overall management very likely contributes to range improvement with the adoption of a more intensive system.

Range Improvement Practices

Some grasslands within the ponderosa pine ecosystem were cultivated for various agronomic crops for a number of years, then abandoned by early settlers. Plow lines on these areas are often apparent almost 100 years later, and poor forage species still predominate. Elsewhere, heavily grazed open parks also often support only poor forage species. Seeding of a variety of forage species can restore these areas to a highly productive condition in a few years (fig. 5).

Research emphasis on seeding of depleted ponderosa pine ranges has centered largely on planting techniques, species adaptability tests of both native and exotic species, and management aspects such as season and intensity of use. The results have provided sound recommendations of when, where, what, and how to seed. The most promising species for Colorado are listed in table 4.

Seeding success was closely related to the degree of seedbed preparation and removal of competing vegetation. Seedbed preparation with a moldboard or brushland plow, or a heavy offset disk has often resulted in excellent stands.

Early spring and mid- to late-fall plantings have given the best stands in lower elevations of the pine zone in Colorado. In the upper part of the zone, seeding in April and May or September and early October on well-prepared seedbeds is usually best.

Management studies on seeded areas have shown a mixture containing crested wheatgrass with yellow sweetclover plus smooth brome or intermediate wheatgrass as secondary species can be recommended for sustained forage and livestock production in the Front Range. Once established, grazing of these ranges can begin in the spring when maximum leaf length of crested wheatgrass plants

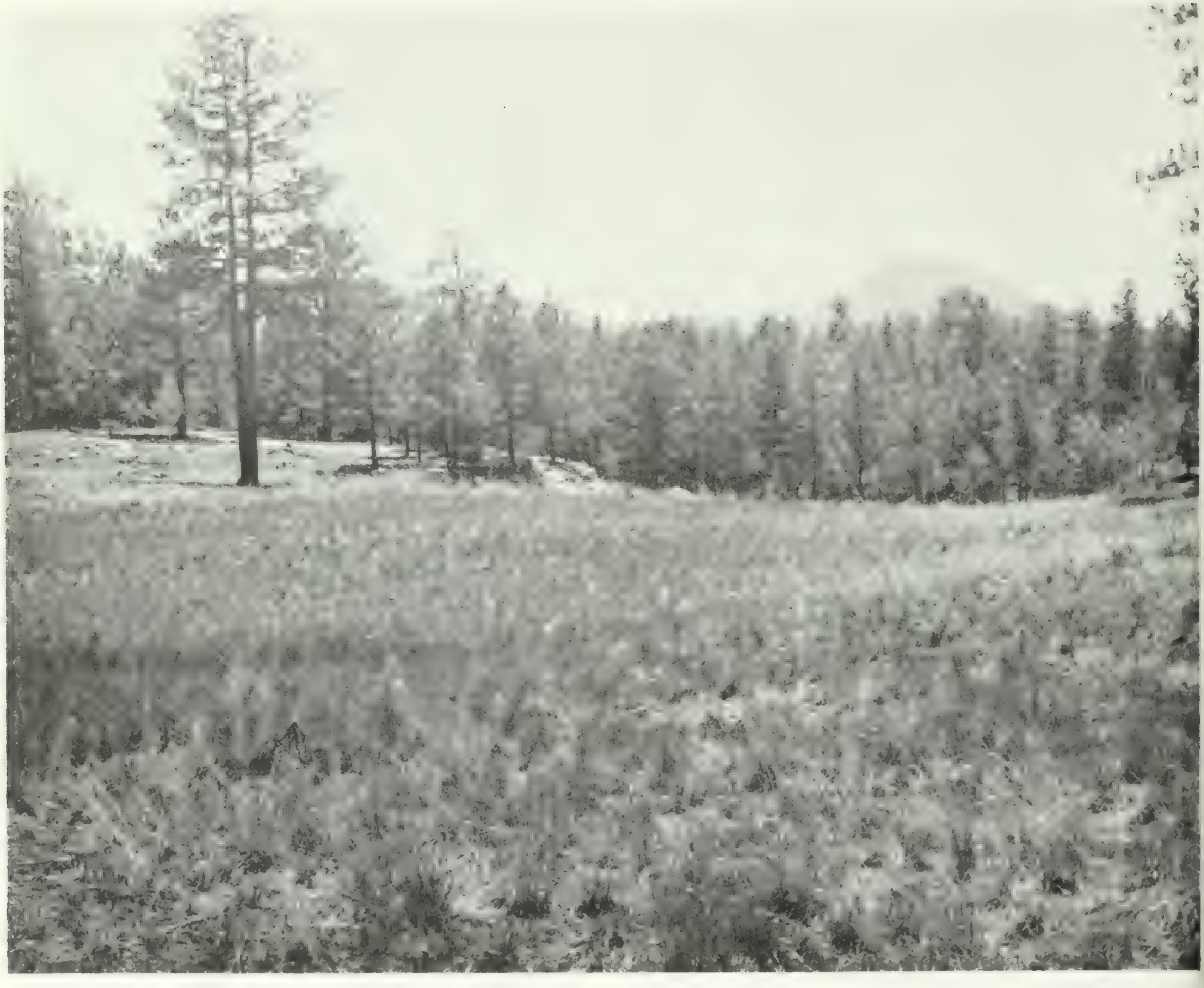

Figure 5.—Grassland parks in the ponderosa pine-bunchgrass ecosystem can be returned to a productive condition by seeding one or more forage species.

Table 4.--Success of six species used in range seedings in the ponderosa pine zone

Species	Times seeded	Seedings by class				
		Excellent	Good	Fair	Poor	Failure
Crested wheatgrass	265	64	127	27	21	26
Smooth brome	195	31	88	25	24	27
Yellow sweetclover	153	17	60	26	30	20
Alfalfa	34	4	25	--	1	4
Timothy	16	--	8	2	4	2
Intermediate wheatgrass	13	7	5	1	--	--

verages approximately 4 inches. They can continue o be grazed seasonlong to a 2-inch stubble height, vhich is approximately 65 percent of the total forage veight.

Crested wheatgrass stands have been grazed to a -inch stubble in the spring or fall without depletion. n New Mexico, utilization of up to 77 percent of he herbage had no deleterious effect on crested vheatgrass stands grazed only in the spring.

For very early feed, Russian wildrye may be eeded in pure stands in the Front Range. Animal veight gains will usually be smaller than on ranges eeded to a mixture of species, however. Grazing to pproximately a 3-inch stubble height is recomnended for Russian wildrye to avoid development of ngrazed wolf plants and local overgrazed areas.

Seeded stands of Sherman big bluegrass produced he highest total beef production and grazing apacity of any seeded species tested at Manitou Experimental Forest near Colorado Springs, Coloado. Special care must be exercised to avoid lanting seeds too deeply. To insure successful stablishment, seeds should be planted into a moist, vell-prepared seedbed in July or August.

The grazing season in which animals make good ains can be substantially increased by including eeded ranges in the management system. Combiations of seeded and native range provide sufficient utrients 10 months of the year.

Cultural practices such as the use of herbicides nd range fertilization can also improve these ranges nd increase grazing capacities. Severely depleted anges are most responsive to these kinds of treatnent.

Several widely recognized range management practices also are applicable to ponderosa pine-bunchgrass ranges: fencing for better livestock control and distribution, development or hauling of water, movement of salt grounds to encourage uniform use, range-riding and construction of trails and driveways to move livestock and improve range accessibility.

Additional Needed Guidelines

Managers and users of ponderosa pine-bunchgrass ranges in the central Rockies have knowledge available that enables them to satisfactorily manage the grazing resource for livestock production. However, additional constraints on conventional uses of this forest-range ecosystem are complicating management. For example, range livestock operators and public land managers are required to provide in their management plans for integration of the multiple products and values that are available in the ecosystem. Because much of the ecosystem is close to population centers and is readily accessible, management must now also accommodate intensified demands for subdivision development, esthetics, wildlife, and a variety of recreation activities.

It is within this framework that research must concentrate on developing, testing, and evaluating knowledge applicable to multidisciplinary management. Prerequisite to it is a comprehensive appraisal of the ecosystem components and their inherent productive capabilities. Land managers must be able to understand and predict the interactions and responses of the abiotic, biotic, and socioeconomic components affected by various management prescriptions.

ARIZONA PONDEROSA PINE-BUNCHGRASS ECOSYSTEM

General Characteristics

The ponderosa pine-bunchgrass ecosystem in Arizona extends from approximately 6,000 to 9,000 feet, varying according to slope and exposure, It is the major forest ecosystem in the State, and, although widely scattered, the bulk of it is found in central Arizona as an unbroken stand for nearly 225 miles. Ninety-six percent of the commercial forest area is in public ownership.

Moisture, which is commonly limiting, comes in two pronounced periods (winter and summer). In the summer, moisture-bearing winds from the Gulf of Mexico result in frequent, high-intensity, localized thundershowers in the mountainous region of central and southeastern Arizona. Winter precipitation is primarily from storms that move inland from the Pacific Ocean, and drop most moisture as snow in the high mountains of the central and northern parts of the State. Annual precipitation averages 20 to 21 inches, with a range of 19 inches to 25 inches.

Much of the ecosystem occurs on the relatively flat topography of the Colorado Plateau Province, and in an altitudinal belt on the isolated mountains of the Basin and Range Province across southern Arizona and New Mexico. The sedimentary formations of the Plateau are interrupted by igneous structures, including some large central-type volcanoes, numerous cinder cones, and lava-capped plateaus.

Soils on which the ecosystem has developed are derived from both igneous and sedimentary rocks. Soil characteristics that influence available moisture tend to be the most important to the vegetation. The more porous soils are generally more productive.

Soils on the Colorado Plateau vary from fine to moderately coarse-textured sandy loams, often with clay loam to clay subsoils. Frequently they contain admixtures of gravel and large volcanic boulders. In some areas, cinders of varying depth overlay a fertile clay soil.

Within the Basin and Range Province, surface soils are mainly sandy loams which vary in depth. Many are gravelly, stony, and porous. Rock outcrops are frequent.

Ponderosa pine forest occurs mainly in uneven-aged stands of small even-aged groups ranging up to several acres (fig. 6). In central and northern Arizona north of the Mogollon Rim, the ponderosa pine forests usually contain few trees of other species, and often appear parklike with a grass understory. The southern forests tend to have a more complex composition of conifers and hardwood; parklands with grass and/or shrub understories are rare. In climax forests understory shrubs may be lacking to fairly common. A number of perennial forbs are typically found in the ponderosa pine forests more or less throughout the State.

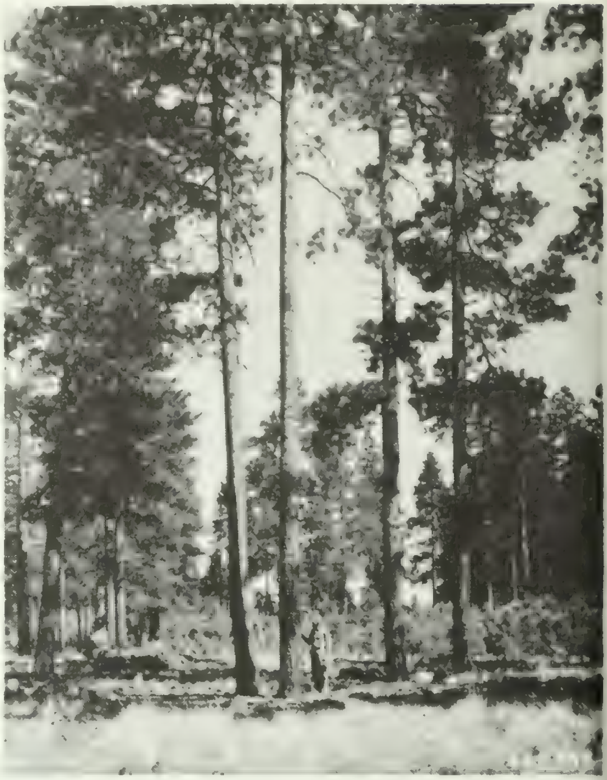

Figure 6.—Southwestern ponderosa pine occurs as irregular, uneven-aged stands consisting of small even-aged groups. Herbaceous understory is prominent where the tree canopy is not too dense.

The characteristic grass aspect of the understory of ponderosa pine forests on the Colorado Plateau is dominated by Arizona fescue and mountain and screwleaf muhlys. Other species may be abundant locally or scattered through the understory cover. The vegetation type supports populations of elk, mule deer, turkey, and tassel-eared squirrels.

The successional pattern of the major portion of the type progresses through eight stages, from annual plants to the stage where the site is dominated by long-lived trees with a herbaceous bunchgrass understory. Because livestock grazing exerts a selective influence upon herbaceous plant communities, the prevailing plant life-forms of each lower successional stage is progressively less susceptible to grazing damage. Species which either escape or withstand a high degree of grazing abuse may persist as minor components of the herbaceous composition of the more advanced successional stages.

Secondary succession of the understory may or may not retrace the course of deterioration, and may equire many years even under improved livestock nanagement. On sites protected from grazing, erennial grasses may become reestablished simulaneously with various perennial forbs and halfhrubs. Ponderosa pine seedlings may become estabished during the early stages, and the forest opening an progress directly to a forest-dominated condiion.

As forest density increases, production of the erbaceous understory may decline from 1,000 ounds per acre in forest openings to 50 pounds per cre in dense stands. This inverse relationship is enerally curvilinear. Overstory reduction usually rings a rapid response of herbaceous vegetation. Ierbage production peaks about 6 years after ogging, and on selectively logged areas will exceed hat of unlogged areas for 11 to 15 years. The largest erbage response to annual weather differences can e expected where timber overstory dominance is ninimum.

Fire in the southwestern ponderosa pine type has een a subject of controversy. Some have felt that ire has resulted in reduced timber production, while thers claim that periodic natural fires have been mportant in developing and maintaining the "nornal" stand structure of the type. The change since he early 1900's from open stands to dense thickets f young trees has been in part due to protection of he forest from fire. Fires cause the greatest damage n these stands.

A wildfire on the Wild Bill Range in Arizona aused almost complete mortality of trees in an nthinned young stand (126 square feet per acre asal area), but no significant reduction where the tand had been previously thinned to 20 square feet asal area per acre and the fire remained on the round. There were large increases in forage proluction for livestock and wildlife where the tree anopy was eliminated. However, the postfire proluction was approximately the same on both the urned and unburned areas of the thinned stand. Vhere the burned, unthinned stand was seeded to rchardgrass and intermediate wheatgrass, herbage roduction exceeded 1,000 pounds per acre, ovenlry, or approximately 400 pounds more than the nseeded area.

Prescribed burning for fuel reduction and silviultural purposes also benefits forage production and tilization in moderate to dense stands. Experiments uggest that the fire should consume the total depth f the forest floor to increase herbage production ppreciably.

Information on forage nutrition of Arizona ponlerosa pine ranges has been developed at the Wild Bill Range. Crude protein is consistently higher in orage growing in the open as compared to that nder a timber overstory. After peaking in June, it teadily declines through the summer season. The seasonal trend and overstory relationships for phosphorus in the forage are less consistent. No seasonal or overstory trend was detected in mineral content of the forage.

A large portion of the Arizona ponderosa pine ecosystem is grazed in the summer. Cold temperatures and deep snow generally preclude its use at other times. However, some National Forest allotments in the more southern portion of the region are used yearlong or in other seasons.

Few data are available on the economic and operational characteristics of cattle ranches in Arizona and New Mexico which are specific for ponderosa pine bunchgrass ranges. Size of the ranch operation and carrying capacity of the land both strongly affect the cost efficiency of producing beef. Ranches averaging 200 animal units (AU) do not have the income to pay interest costs nor do they provide a full return to labor. Ranches do not attain near maximum economics of scale until they reach about 800 AU.

How grazing affects water yield and quality is an important question, as the ponderosa pine type is the source of nearly half the streamflow in the Salt River watershed in Arizona. Grazing a watershed in Arizona that was converted from ponderosa pine to a grass cover has not resulted in increased water yield.

This lack of response, which was obtained on heavy-textured volcanic soils, has not been consistent on sedimentary soils. The effects on erosion and sediment movement are likewise variable. The effect of fecal contamination of water when riparian habitats are grazed is unknown.

The primary impact of grazing on timber production is the potential damage to regeneration, especially where grazing is excessive. Often, intensive silvicultural management can benefit both timber production and forage production.

Parks and forest openings in the Arizona ponderosa pine type are preferred by cattle and elk, and if they are not too large, by deer also. The mutual preference creates potential for competition. Intensive livestock grazing can cause both deer and elk to avoid an area, but light to moderate grazing may have little effect on big-game animals.

Range Management Prescriptions

Stocking and Forage Use

Ponderosa pine naturally grows in groups with interspersed small forest openings and larger open parks. Grazing is normally most intensive in forest openings or where the forest canopy is sparse.

Factors that influence grazing of pine-bunchgrass ranges include: (1) distance from water, (2) steepness and length of slope, (3) trails and other access routes, (4) density of the timber stand, (5) floristic composition and season of use, and (6) range condition.

Range condition is related to the kind and abundance of perennial bunchgrasses. As less desirable species that escape or withstand heavy grazing become more prominent, range condition declines. Increasing timber density has little effect on the floristic composition of the herbaceous species.

Arizona fescue flowers about 1 month earlier than mountain muhly, similar to the development of the two species in the pine-bunchgrass type of the central Rockies. This flowering difference is reflected in the seasonal forage preferences of the grazing animals. In northern Arizona, Kentucky bluegrass, Arizona fescue, and mountain muhly are preferred species, while blue grama and prairie Junegrass are least preferred. Proper grazing of the forage species on Arizona ponderosa pine ranges appears to be about 30 to 40 percent.

Grazed-class photo guides and grazed-plant methods are useful in estimating forage utilization. On National Forests in the Southwest, zones of forage production and utilization are mapped from ocular estimates and clipping and weighing herbage over several seasons. Actual stocking records combined with these map records provide a basis for arriving at proper stocking.

Grazing capacity varies considerably, but potential carrying capacities of Arizona ponderosa pine ranges have been estimated at 5 to 8 acres per animal unit month. Averages on National Forest land by condition class range from 7 acres per AUM for range in good condition to 41 or more acres per AUM on the poorest ranges. Approximately 45 percent of the ponderosa pine range is in less than fair condition.

Grazing Systems

Several authors have recently reviewed the value of specialized grazing systems. Advantages and disadvantages encountered on Arizona ponderosa pine ranges are similar to those on other range ecosystems.

Most systems provide for (1) periodic deferment or rest to allow desirable forage species to regain vigor, (2) more uniform use of the forage resource through better livestock distribution, and (3) the integration of seeding and control of undesirable species into the grazing plan without additional fencing for grazing control. The expenses of additional livestock water and for the additional units that are required must be anticipated if a specialized system is adopted. Major points to consider in selecting a grazing system include:

- Kind and class of animal to be grazed.
- Kind, amount, and phenology of vegetation.
- Amount and seasonal occurrence of rainfall.
- Topography and elevation.
- Length of growing season.
- Kind and characteristics of soil.
- Costs for fencing, water development, and other range improvements.

Range Improvement Practices

Forage yields on ponderosa pine ranges can usually be improved by management practices designed to improve range condition trend. Where improvement is apt to be slow, seeding of desirable forage species can rapidly restore range productivity, correct seasonal deficiencies in forage supplies, and retard erosion on disturbed sites such as logging roads or recently burned areas.

Undesirable plants are often not the serious problem they are on other range ecosystems. However, removal of competing vegetation is recommended for seeding success. Selection of potentially productive sites, proper planting of adapted species at the proper season, and the use of viable seed are also basic to seeding success.

Disk-type plows have generally proved best for preparing sites and removing competing vegetation without excessive disturbance of the seedbed. Seed should be drilled wherever possible.

Seeding rates vary by species, but generally average 8 to 10 pounds per acre. Plantings from about the middle of June to the middle of July, just prior to the summer rains, have been most consistently successful in New Mexico and Arizona. In some areas, fall or early spring seeding can be recommended where seedlings can be sufficiently established to survive the late spring-early summer dry periods. The species to be seeded should be selected in part upon the forage requirements of the management plan, including when they will be grazed. Generally, crested wheatgrass and intermediate wheatgrass have shown the widest range of adaptability. Once established, big bluegrass can produce outstanding yields. In areas with annual precipitation above 25 inches, orchardgrass, smooth brome, and tall oatgrass may produce a more palatable and nutritious forage; 18 inches of precipitation may be sufficient to establish stands of orchardgrass and tall oatgrass.

On disturbed sites, long-lived sod-forming grasses such as intermediate wheatgrass and smooth brome will give maximum protection. Where quick, but temporary, erosion control is needed until pine seedlings are established, short-lived grasses, sweetclover, and annual mustards should be considered.

New plantings need protection for at least the first two growing seasons. Thereafter, the seeding should be grazed and managed so that forage production can be maintained. Other techniques for improving forage yields include fertilizer applications and wat spreading. There has been little documentation of the effectiveness of these techniques in the Arizona ponderosa pine type, however.

Additional Needed Guidelines

Emerging demands for the range resources in the Southwest appear to be dominated by the quests for recreation and maintenance of environmental quality. The ponderosa pine ecosystem is increasingly popular for people seeking escape from the heat in the desert metropolitan areas. Concomitantly, the public is becoming more cognizant of the management of these lands in public ownership.

The recreational opportunities of these rangelands may provide more economic benefits to the rural communities than attempting to attain maximum ivestock production. Range livestock operations, maintenance of environmental quality, and other uses of ponderosa pine-bunchgrass ranges are seldom ncompatible if the resource is wisely managed.

A thorough knowledge of the managed ecosystem is necessary to achieve an optimum combination of uses. The resources need to be characterized, classified, inventoried, and monitored. With such a base, they can be adapted to new or changing programs and policies, and more intensive management practices.

More detailed information is needed, however, on the beneficial and detrimental effects of grazing in relation to wildlife populations and recreational use of ponderosa pine ranges. In addition, more specific knowledge is needed about which grazing system will bring about the most rapid recovery of range condition for different condition classes across broad site (or habitat-type) differences on Arizona pine-bunchgrass ranges.

An optimum combination of uses requires a more refined analysis of the social and economic aspects of range use of the ponderosa pine ecosystem. Investment and returns for entire ranch operations as well as specific management activities and improvements must be meshed with the constraints that are being placed on the historic uses of the resource, particularly that in public ownership.

General Characteristics

Mountain grasslands are intermixed with timber stands between the upper limits of the ponderosa pine forests and the alpine ecosystem, usually at elevations from 8,000 to 11,500 feet. They are associated with spruce-fir, lodgepole pine, and aspen forest types in Wyoming, Colorado, New Mexico, and Arizona (fig. 7).

These forest types occupy an estimated 15 million acres in the central and southern Rocky Mountains; mountain grasslands comprise not more than 10 percent of the total.

Long winters with deep snow and short, cool growing seasons characterize the climate. Average annual precipitation varies from 20 to 40 inches. Summer rainfall averages 6 to 10 inches. During the warmer summer months, temperatures average about 50° to 55°F.

Snowmelt during April or May usually saturates the soil mantle. With rising temperatures in late spring, plant growth is rapid and reaches its maximum biomass in late July. Killing frosts usually occur by early September.

Soils of mountain grasslands are variable due to diversity of parent materials and the complex geomorphic conditions under which they developed. They resemble prairie soils in that the A-horizon is dark brown, relatively high in organic matter, slightly acid, and usually well drained.

An extensive segment of the mountain bunchgrass community is characterized by Thurber fescue. This species is often dominant from southern Wyoming southward through Colorado into northern New Mexico and Arizona. Thurber fescue is sensitive to heavy grazing, however, and may be replaced by several other small bunchgrasses.

Another segment, the Wyoming bunchgrass community, occurs to the north in the central Rockies. Idaho fescue associated with bluebunch wheatgrass and sagebrush typify the plant cover. The vegetation may vary greatly with changes in soil texture or exposure; less conspicuous differences occur with gradual changes in elevation or other features of the environment.

Encroachment of trees on typical grassland sites is slow because of strong competition for moisture from the large, vigorous bunchgrasses and other herbaceous plants, low temperatures, soil heaving, and other limiting factors. Fire also may play an important role in restricting the invasion of trees. Where grasslands intermingle with forests, differences in site characteristics are usually less pronounced.

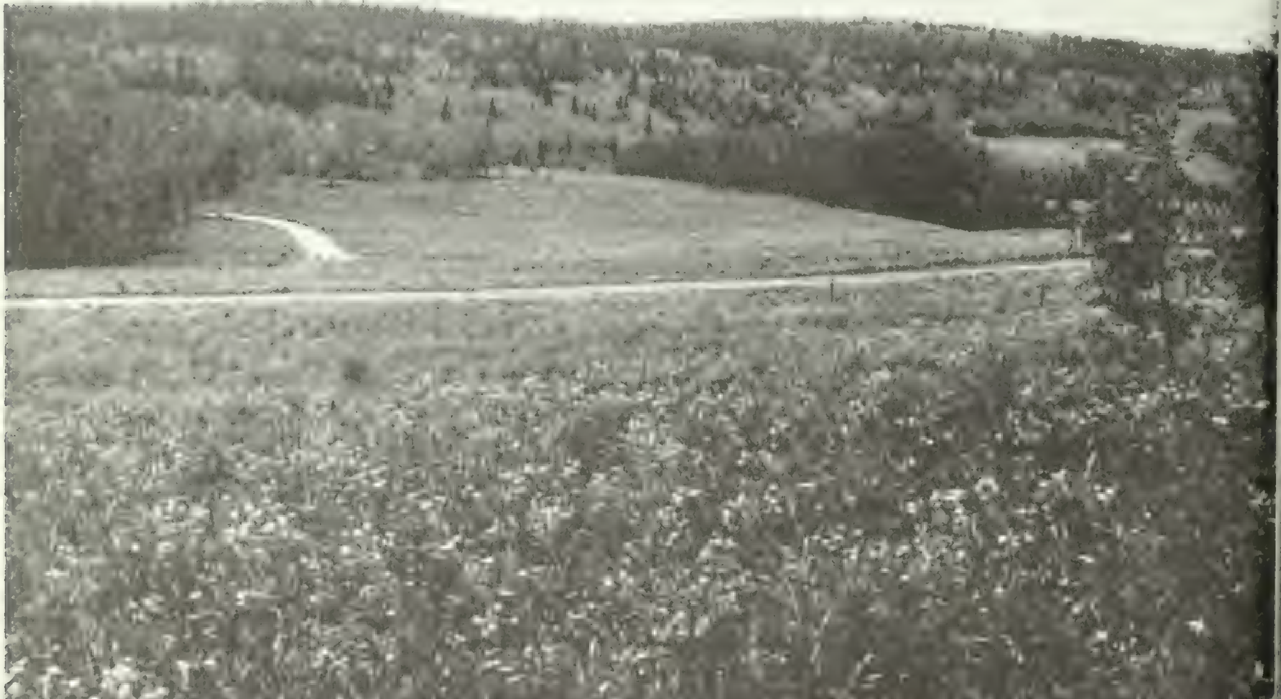

Figure 7.—Mountain grassland parks occur intermixed with high-elevation forests.

Floristic composition varies with site characteris- cs and grazing history. Forbs tend to be more rominent at higher elevations, however, and shrubs t lower elevations within the mountain grassland one. Forbs are characteristically absent from bunch- rass ranges with a long history of sheep use. nterstices between the grass plants are occupied by tter or bare soil. Annual plants seldom are abun- ant except on recently disturbed or severely over- razed areas.

Herbage production of 1,000 to 2,000 pounds per cre is common on mountain grasslands, and yields ccasionally exceed 3,000 pounds per acre. Pro- uctive sites usually support a relatively dense cover f bunchgrasses and tall forbs; shrubs may be locally bundant.

Mountain grasslands in the central Rockies were itially grazed by domestic livestock about 100 years go. By 1900 practically all of the available high- levation lands were being grazed, and some already ad been overgrazed. Regulation of grazing on them egan with establishment of the National Forests in ne early 1900's. However, these and other range- nds received maximum use in meeting the demands f World War I. Present use of National Forest angeland in the West is only about one-fourth of ne former high level. Nevertheless, the grazing of igh-altitude rangelands continues to be essential for neeting the annual forage requirements of many vestock ranches in the central Rockies. Most of nese ranges are grazed by cattle, although they rovide nutritious forage for sheep as well.

Mountain grasslands and adjacent forests also rovide habitat for game and nongame animals. The se of these areas by wildlife is influenced by the nanner and degree to which they are grazed by vestock. Elk will graze with cattle during the ummer where there is an adequate food supply.

Livestock grazing enhances the scenic interest and ttractiveness of mountain grasslands to some eople. To others, livestock are a nuisance, especial- y in the vicinity of campgrounds; sometimes there is nutual disturbance. Recreation developments may educe the amount of rangeland available or suitable or grazing, but in general, conflicts between grazing nd recreation do not appear to be serious or wide- pread.

The mountain grassland ecosystem of the central ockies is an important source of water to millions of eople hundreds of miles away. It is locally impor- ant for many small communities. Consequently, nanagement practices which impact upon the stor- ge and delivery of water for downstream domestic, ndustrial, and agricultural uses are of critical sig- ificance.

Range Management Prescriptions

Stocking and Forage Use

Present knowledge is generally adequate for deciding what constitutes a permissible level of grazing on mountain grassland. Use of the more productive and palatable grasses, such as Idaho fescue, should not exceed 40 to 45 percent on range in good condition grazed seasonlong. Palatable and nutritive forbs also may comprise a sizable and valuable part of the cattle diet. To utilize this class of forage more fully, stocking may be somewhat heavier earlier in the grazing season than in the fall when many forbs dry and shatter. Grass use in fall tends to increase as forbs become less readily available. Bunchgrasses produce little regrowth when they are grazed after flowering. Under continuous, seasonlong use, the grazing capacity of mountain grassland in good condition is about 1.5 acres per animal unit month. About 2.5 acres per AUM may be a reasonable overall estimate for the type.

Contingent upon the depth of the snowpack and the rate at which it melts, most ranges are ready for grazing between mid-June and mid-July. Range readiness guides for mountain grasslands usually stipulate that important perennial grasses be headed out and that the soil be sufficiently firm and dry to avoid trampling damage. Grazing is often terminated in early fall, but may be dictated by weather and/or quantity and quality of forage.

As on other ranges, selective grazing on mountain grasslands may weaken the more palatable plants and favor the less palatable ones. Because of the competitive advantage thus gained, nonpalatable plants often become more prominent on heavily grazed ranges. Discontinuance or reduction of grazing may serve only to retard or prevent further range deterioration without necessarily shifting the competitive advantage to palatable plants over a short time span. Consequently, relatively unpalatable plants may persist for years.

Range deterioration is indicated by many changes. In its early stages, an increase in forbs or secondary smaller grasses usually accompanies a decrease in primary grasses such as Thurber fescue and Parry oatgrass. Total cover may change very little, and occasionally it increases. Herbage production and litter tend to decrease slightly, and bare soil increases. In more advanced stages of deterioration, reductions in ground cover and herbage yields become more pronounced. Less evident, but equally important, are changes in plant growth and site characteristics. For example, there may be changes in (1) plant vigor of the major forage species, usually expressed through a reduction in the number and height of grass flower stalks or length of leaves, and (2) soil stability, as evidenced by litter accumulation, surface runoff, and erosion. Other factors sometimes considered are changes in size of grass clumps, abundance of plant seedlings or young plants, frequency of dead or dying plants, arrangement of plant colonies, amount of forage produced, and current degree of grazing.

Grazing Systems

For many years, mountain grasslands were grazed closely and continuously from the time snow melted until snow or cold weather forced livestock to lower elevations. Continuous grazing but with more moderate stocking is still widely practiced from the time the range is ready until fall. This system is best suited to small range units in relatively good condition. An advantage claimed is that cattle gain more weight than under other systems which require periodic movement of the herd. Areas of livestock concentration may be a problem, however, and palatable plants may be overgrazed and soil erosion increased as a consequence of topographic features, vegetation patterns, and watering places.

Various systems of grazing have been advocated, primarily to improve range condition and obtain more uniform use of the range. Some form of a rotation, deferred-rotation, or rest system can be employed to advantage on most ranges large enough to justify subdivision and development of necessary stock water. Decision as to the best system must be based on local conditions and circumstances.

Desirable features of these more intensive systems are: (1) from a biologic standpoint, they periodically rest important forage species from grazing during the growing season, and (2) from a management standpoint, they provide more uniform use of the range when it is grazed. Range units stocked heavily for a short period usually provide more usable forage than if stocked more lightly for a longer period. Furthermore, control of undesirable range plants and range seeding usually require protection from grazing for a year or so, but additional fencing to protect the investment may not be needed when the area is integrated into a grazing system that provides for periodic nonuse of the range.

Fencing of mountainous rangeland is expensive, and may preclude intensive management systems on some areas; costs of fencing range from $1,500 to $2,200 per mile. Adoption of a system may further be restricted by differences in elevation and plant development, natural barriers, unequal distribution of vegetation types, and other factors that do not allow individual units to supply their share of forage when needed.

Range Improvement Practices

Seeding of mountain grasslands may be needed and justified if satisfactory range condition cannot be restored within a reasonable time through grazing management or control of undesirable plants. Scarcity of desirable plants, suitability of the site for seeding, need for additional forage or ground cover, ability to protect and manage the seeded area, and costs and returns from seeding are factors to be considered. An estimated 5 percent of the mountain grassland area in Colorado is in need of seeding, and most of the better sites can be seeded on the basis of available guidelines. Numerous species are adapted to mountain grassland sites. Seeding costs have been estimated at $5.50 to $8.50 per acre.

Guidelines are available for controlling severa noxious species on mountain grasslands. Spraying to control broad-leaved species and increase grass production has coincidentally reduced pocket gopher populations by reducing their food supply. However herbicidal control of certain poisonous plants, particularly larkspur, has been generally ineffective o impractical.

Rangelands sprayed with herbicides are often protected from livestock for 1 to 3 years to obtain the greatest possible recovery of the forage grasses Recent findings indicate that comparable improvement may be obtained under moderate grazing without rest.

Mountain grasslands provide nutritious forage fo livestock during most of the summer grazing period However, nutrient content of the forage and anima weight gains decline with advance of the season, an may approach minimum levels recommended fo maintenance of cattle before the animals are taken t lower ranges in the fall. Grass yields, crude protei content, and palatability may be increased unde certain conditions by fertilizing the range with nitrogen. Nitrogen generally favors growth of grasses while phosphorus and potassium encourage growt of legumes. Ample soil moisture is required fo fertilizer to be effective. On relatively infertile soil best results may be achieved by fertilizing in conjunction with the control of noxious plants.

Dead organic matter may accumulate in dens lightly grazed stands of Thurber fescue. Buildup litter lowers soil temperature, which in turn reduc bacterial activity, ties up nutrients, and slows th general nitrogen cycling process, particularly durin cool, wet years. Under such conditions, burning ma increase the quantity or improve the quality of forag Certain rodents, which tend to become more abudant with increases in litter, possibly could reduced through prescribed burning. Prescrib burning also offers a potential means for controlli grassland insects and diseases.

Practices to improve cattle distribution and the sability of mountain grasslands are similar to those escribed for other ecosystems. Rough topography nd elevational differences, which noticeably affect lant development, complicate distribution and man-gement of livestock.

Additional Needed Guidelines

Livestock grazing is desirable on mountain grass-nds. Even though its contribution is comparatively mall in the national context, these ranges provide a aluable segment of the annual forage requirements f many ranch operations which furnish calves as eeder animals to help supply the nation's demand for eef. Other demands for mountain grassland prodcts and attributes can be expected to increase, owever, and adjustments in livestock grazing will e needed to accommodate those uses.

Management of the resources of the subalpine one have been largely single-use oriented; that is, ood products from the forest and livestock products om the intermingled grasslands. Much of the nowledge necessary for efficient, single-use manage-ent is available, but not all is readily accessible the land manager. Moreover, this information is eeded in a context that illustrates how various land anagement practices influence the productivity and uality of all resources, the complex processes and interactions involved, and the balance of uses and products.

Within this framework, specific areas are in need of further amplification and/or refinement. Understanding of the vegetation/soil responses under various grazing systems that might enable earlier use of the range is needed to insure maintenance of inherent site productivity. Similarly, improved guidelines for estimating site capability are needed to complement estimates of carrying capacity of areas for livestock, wildlife, and people. Also, the influences of fire, phytotoxins, rodents, and soil characteristics on composition and succession of mountain grassland vegetation deserve further study.

Opportunities for, and long-term effects of, range improvement through manipulation of individual species, or groups of plants, need exploration. For example, research is needed to determine methods for controlling or replacing less desirable species with more desirable ones, to meet not only the requirements of livestock but also those of recreationists and wildlife. Furthermore, the responses of seeded ranges to different systems of grazing need to be determined in conjunction with the economic evaluation of seeding. Information is also needed that will insure rapid revegetation of areas disturbed by ski developments, road construction, or other peculiarly difficult sites. Much remains to be learned about the potentials and limitations of plant cover manipulation, and their overall effects on the environment.

ALPINE ECOSYSTEM

General Characteristics

The alpine ecosystem occurs from the upper limits of tree growth to the mountain peaks, which may exceed 14,000 feet in the Rocky Mountains (fig. 8). The transition from forest to alpine may be abrupt, or it may be a rather broad ecotone marked by low-growing, poorly formed trees interspersed with characteristic herbaceous and shrubby alpine species. In the Rocky Mountains the alpine is usually above 11,800 feet in northern New Mexico, 11,000 feet in northern Colorado, 9,800 feet in northern Wyoming, and as low as 7,500 feet in northern Montana.

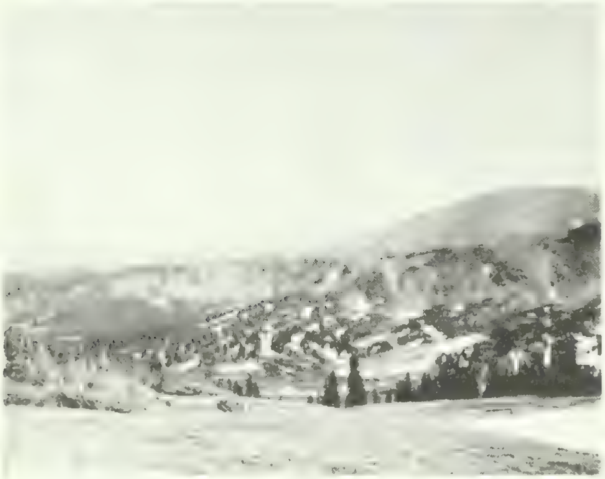

Figure 8.—Low-growing herbaceous and shrubby species characterize the alpine ecosystem above the coniferous subalpine forests.

The alpine landscape is often characterized by rugged, broken topography with rocky, snowcapped peaks, glaciers, spectacular cliffs, and talus slopes. Many areas, however, are gently rolling to almost flat.

Alpine soils are, in general, much less uniform than the soils of lower, level areas. Part of this nonuniformity is due to the great variability of terrain, and part to the strong freezing and thawing processes responsible for stirring and sorting the soil and rock fragments. Soils range from rocky and gravelly lithosols with little or no development to boggy, organically derived peats. Mineral soils on well-drained areas with a good vegetative cover generally show considerable profile development. Permafrost may be present at relatively shallow depths.

The most important factor controlling the distribution and growth of alpine plants is available soil moisture. Soil moisture depends to a large extent on the snow accumulation pattern, which results from the interaction of wind and topography.

Precipitation during the growing season may have little effect on the growth of alpine species. Often it comes as high-intensity rains with consequent high runoff and lack of penetration into the root zone.

The alpine zone is seldom without wind; average windspeeds of 25 to 30 miles per hour are common. Wind not only influences the snow distribution pattern of the alpine zone, but plants are killed or damaged both by mechanical abrasion from wind-driven soil particles and by desiccation. Wind erosion removes the fine soil particles and leaves coarser particles as mulch.

The temperature regime is highly variable, but low temperatures are characteristic. Temperatures at or near the ground surface may be relatively warm, however. There is a marked diurnal temperature regime, and a pronounced shady slope-sunny slope variation.

In comparison to more complex floras of lower elevations, usually no more than 200 to 300 species are present in the alpine zone of a given mountain range; many of these are common to most alpine areas of a region. Grasses and sedges are almost ubiquitous. Additional families with wide alpine distribution are saxifrage, rose, mustard, buckwheat and pink. Usually these are represented by herbaceous perennials with large root or stem storage systems. Annual plants are rare. Most shrubby species are members of either the willow or heath families. The shrub life form is not common, however.

Little is known of the environmental condition necessary for successful reproduction. Seed production and seedling establishment are sporadi because growing season conditions are frequentl unfavorable, although in some years abundant see crops are produced. Seedlings become establishe both in open areas and within the crowns of other plants, particularly low-growing cushion plants.

Biomass varies considerably from year to year an from site to site. Xeric, exposed sites often produc less than 100 pounds per acre aboveground, while o more favorable sites production may exceed 3,00 pounds per acre. Mesic turf sites will averag between 900 and 1,800 pounds per acre.

About 80 percent of the biomass of alpine plants below ground. Forbs appear to have a proportional greater amount of underground biomass than gra or grasslike species.

The alpine growing season is only 30 to 75 da long, but the rate of increase of standing crop ma exceed 50 pounds per acre per day. This rate comparable to that of many low-elevation communities.

Alpine species seem to have a wide ecological mplitude, and can occupy what appear to be diverse abitats. The classic concepts of climax and succesion as developed in warmer, low-elevation regions not appear to be applicable in the alpine zone.

Most of the alpine zone is in public ownership. heep are the principal domestic livestock that graze e alpine allotments; cattle grazing is limited ecause cattle are subject to heart damage (brisket isease) on high-altitude ranges.

The number of sheep grazing the alpine allotents in the central and southern Rockies has eclined steadily since World War II. Inaccessibility, gh costs of operations, shortage of dependable erders, market conditions, and closures of allotents to domestic sheep grazing for range protection ave contributed to the situation.

Sheep diets usually consist of a relatively large umber of species, which provide high-quality rage. Overall, forbs make up the bulk of the diet, e proportion being related to their relative availility. Consumption of grasses and sedges increases the latter part of the grazing season as forbs ature.

A number of large and small mammals and birds ilize the alpine ranges for summer habitat, while hers are residents throughout the year. Common ecies include elk, deer, mountain sheep and goats, ka, marmot, pocket gopher, and ptarmigan.

Range Management Prescriptions

tocking and Forage Use

Alpine ranges have been grazed by sheep since e late 1880's. As numbers of domestic livestock creased on the western range, animals moved to gher elevations, more or less following the receding ow line each spring. Sheep were usually grazed in ghtly grouped bands and bedded for several nights the same location. These practices resulted in rage depletion and soil erosion from excessive ailing and trampling. Currently, areas with slopes excess of 40 percent are considered nongrazable ecause of possible soil damage (fig. 9). Large ickets of upright willows are usually avoided, as e slopes below late-lying snowfields where bare il would be exposed to trampling.

Under present management, sheep begin grazing ost alpine allotments between July 10 and 15, and main there for approximately 60 days. Bands sually consist of approximately 1,000 ewes with mbs under the direct supervision of a herder.

Forage utilization by domestic sheep is usually ght. Recommended stocking rates for alpine ranges ry from 0.25 acre per sheep unit month on range in cellent condition to 5.5 acres on range in low-poor ondition.

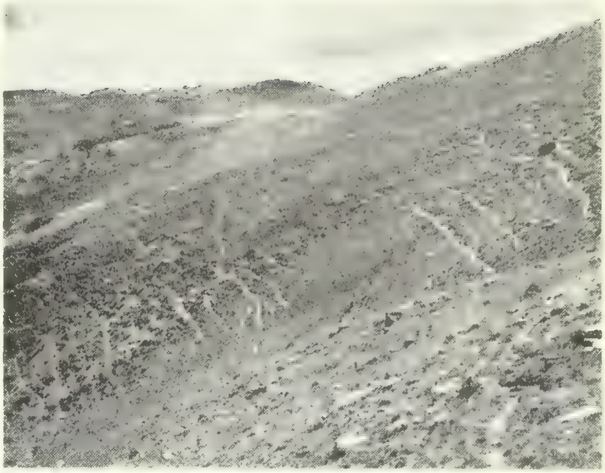

Figure 9.—Grazing and trailing by domestic sheep over steep slopes have caused excessive soil erosion. Abused areas are slow to recover because of the harsh environment.

Grazing Systems

Specialized grazing management, such as deferred or rotation systems, can be achieved by regulated herding. Planned movement of the band can achieve almost any pattern of grazing desired within constraints imposed by topography and access. Most current herding practices permit the sheep to graze while loosely bunched (open-herded) as the band moves slowly, but steadily, in a prescribed direction. Direction is determined by guiding the movement of the lead animals rather than herding the band from the rear. Most management plans stipulate the band will graze a given area only one time during the grazing season. One-night bedding on a well-drained site near where the band finishes grazing for the day is recommended. Salt is usually made available on the bedding ground.

"Herderless" management, where the animals are allowed to distribute themselves and graze according to their own wants, is sometimes practiced on alpine ranges. In these cases topographic features usually restrict movement of the animals beyond the allotment boundary; short sections of fence are sometimes required where terrain features do not confine their movement within the allotment. Claimed advantages are a wider distribution of animals over the range, elimination of concentration on bedgrounds, and a reduction of trailing damage. When unherded, the sheep have a tendency to graze the drier, rocky sites in preference to wet meadows, although the latter have greater forage production. Although better weight gains on lambs have also been reported, research in progress in northwestern Wyoming indicates no difference in lamb weights between herded and nonherded bands. In this study the unherded bands usually moved as a single unit and tended to use the same areas for bedgrounds. The distributional behavior of these animals may be conditioned by past herding practices on the allotment, or to herding practices to which they are subjected during the rest of the year. The breed of sheep may also influence their tendency to band together.

Collection of unherded sheep at the end of the grazing period can be a problem if they are scattered widely. Sheepmen who follow this system find that the animals tend to drift to lower ranges with colder weather, where they can be gathered at concentration points.

Sheep losses due to predators may be high on alpine allotments. Some experienced sheepmen maintain, however, their losses are no higher with unherded bands than where the animals are under the supervision of a herder. In part, this can be attributed to the lack of competent sheepherders. Also, however, the dispersion of the band lessens the opportunity for a predator to inflict heavy losses on a band at one time.

Range Improvement Practices

Little information is available on the use of herbicides, fertilization, and seeding, or structural additions such as fences, water developments, and trails or roads on alpine ranges. Because forbs are important items in the sheep diet, the use of herbicides that remove forbs is not recommended unless few palatable forbs are present, and the elimination of nonforage species will stimulate growth of grasses and sedges. Under a deferred grazing system where certain areas are reserved for late-season use, forb control might be beneficial since sheep tend to use more grass and grasslike species at this time. In one reported study, the total standing crop was unchanged by herbicide treatment, although the grass:forb ratio was changed from 3:7 to 8:2.

Low levels of available nitrogen have been considered a factor limiting alpine plant growth, although small amounts of nitrogen fertilizer did not stimulate a rapid response. Other soil nutrients seem to be present in fairly adequate amounts.

Adequate stock water is usually not a problem on alpine ranges because of snow accumulation. Where sufficient water is not available to meet the needs of management, springs or seeps can usually be developed.

Since most bands are controlled by a herder, there has been little fence construction on alpine ranges. Where they have been built, initial and maintenance costs are often high, but because of the nature of the terrain only short sections usually are needed.

Roads and trails constructed for access are sources of considerable erosion. Scars persist for many years because of long years of use, poor design, and improper maintenance. Problems are especially serious where they have been built on windswept slopes and across wet snowbank areas and meadows. Skillful engineering design and continued maintenance are required to minimize erosion problems from such construction.

Attempts to revegetate these areas have usually been unsuccessful, but it has been accomplished on some local sites where exposure is not too severe. Seeding for range improvement and increased forage production is not common in the alpine.

Additional Needed Guidelines

The alpine ecosystem has many alternative uses. Management principles and practices determined in other ecosystems must be carefully considered before they are extrapolated to the alpine because of the harsh physical environment and the slow rate of recovery of plant cover and soil stability.

Existing range management principles for grazing of the alpine by domestic sheep are adequate. However, more precise criteria of range condition and trend are needed as a basis for multiple use management. Although certain standards developed for other ecosystems can be applied, the uniqueness of the alpine, including its dynamic environment, requires individual attention. A sound ecological classification of alpine sites is needed as a prerequisite to the development of improved standards.

Evaluation of the impacts of other activities and the value of other products of the fragile alpine ecosystem require careful additional study and monitoring. The system will deteriorate under the impacts of increased numbers of people who are attracted by its rugged beauty and wilderness attributes. Management guidelines for alleviating problem situations are scarce, and standards and criteria should be developed around a framework of sound ecological knowledge.

Other research is needed on the habitat requirements of the yearlong or transient wildlife of the alpine. Opportunities for providing additional habitat for the birds and animals, especially in the forest-alpine transition, have received minimal attention.

Activities that modify or manipulate the alpine snowpack, such as the erection of snowfences to increase the depth of natural snow and large-scale weather modification programs, need to be evaluated and the ecological changes that might ensue identified.

Additionally, controlled experimentation is needed on improvement of localized, deteriorated alpine sites.

RANGE RESOURCE PRIORITY PROBLEMS

Each of the foregoing resumes of existing knowldge for seven major range ecosystems of the central nd southern Rocky Mountains concluded with a rief summary of land management problems that ontinue to exist after more than 70 years of range esearch and management efforts. Because of the omplexity of the range environment, and because of apidly changing demands upon and concerns for nese ecosystems, the land manager today must often eal with new sets of problems that not long ago ere entirely unfamiliar to him. For some areas, ianagement has achieved success in empirically ianaging the resource; unfortunately, such knowldge is often unreported in the literature.

Continuing obstacles to sound, intensified multiple se have surfaced as a result of this review. Solution f the problems listed below will require additional esearch and management, but will have the benefit f rapidly evolving tools in ecosystem synthesis and nalysis. The development of appropriate models hat recognize the many interacting variables of the esource, coupled with sophisticated computer techology, can advance the decision capabilities of the esource manager.

The listing of "problems" that follows has been ummarized from the individual ecosystem reports, hich are the basis for this summary paper. Overall riorities for additional research by ecosystems were stablished by the author of this summary paper. he priorities are based upon (1) his overview of the eeds and opportunities within the seven range cosystems, and (2) consultations and technical eviews of the paper by knowledgeable research and ianagement personnel.

- **Management prescriptions** for the range and related forest resources to coordinate the requirements of wildlife and human amenities in concert with domestic livestock use and other products. Available resource data provide general understanding of certain ecological relationships and range production capability. Where compatible data exist, they are useful in the development of models that help managers evaluate alternative ways of manipulating the resource. However, data for various wildlife, socioeconomic, or esthetic considerations are either lacking or inadequate.
  Ecosystem priority:
  1. Ponderosa pine-bunchgrass (central Rockies and Arizona).
  2. Semidesert grass-shrub.
  3. Mountain grassland.
  4. Chaparral.

- **Vegetation manipulation** to achieve optimum multiple use values from the range resource. Land managers have used prescribed fire, herbicides, fertilizers, mechanical devices, and biological agents to increase forage, water, or wood from the range and related forest ecosystems. Many areas have been seeded to exotic and native herbaceous and woody species to increase production or reduce erosion. Until recently, little attention had been given to the favorable or adverse impacts upon resource values other than conventional products. Opportunities exist for refinement of plant cover management to obtain greater productivity and harmony with all resource uses and values. We need to more specifically identify the proper time and techniques for application of existing and newly developed improvement measures.
  Ecosystem priority:
  1. Southwestern chaparral.
  2. Pinyon-juniper.
  3. Semidesert grass-shrub.

- **Indices and standards** of range resource potentials for better utilization, development, and management. More rapid, efficient, and accurate methods of classifying the ecosystem are needed to monitor change and forewarn the land manager of the need for corrective action. Such methods should provide a more detailed classification of the ecosystem and maps of the habitat units therein. Existing technology and data should be adapted and coordinated with new and improved equipment and technology as it becomes available.
  Ecosystem priority:
  1. Ponderosa pine-bunchgrass.
  2. Semidesert grass-shrub.
  3. Mountain grassland.
  4. Chaparral.
  5. Pinyon-juniper.
  6. Alpine.

- **Intensified ecological and physiological studies** of the range communities and components. Ecosystem synthesis and modeling advances can be employed for developing improved understanding of competitive and successional relationships, nutritional cycling, and energy flows. There are gaps in our knowledge, however, which will require additional field and laboratory research.
  Ecosystem priority:
  1. Pinyon-juniper.
  2. Mountain grassland.
  3. Southwestern chaparral.

- **Improved guidelines** for conventional range management practices. Rangelands produce a salable product that can be marketed, if harvested by a grazing animal. To capitalize on this and contribute to the red meat supply, range management expertise should be expanded to incorporate innovative systems of grazing, techniques to improve animal distribution, dual or multiple use, and recognized range improvement measures integrated with native range utilization.

Ecosystem priority:

1. Mountain grassland.
2. Semidesert grass-shrub.
3. Southwestern chaparral.

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Summarizes a series of comprehensive reports on range management in the seven recognized ecosystems: Semidesert grass-shrub, southwestern chaparral, pinyon-juniper, central Rockies ponderosa pine-bunchgrass, Arizona ponderosa pine-bunchgrass, mountain grassland, and alpine. Includes what is known, what can be recommended, and what additional information is needed for each ecosystem.

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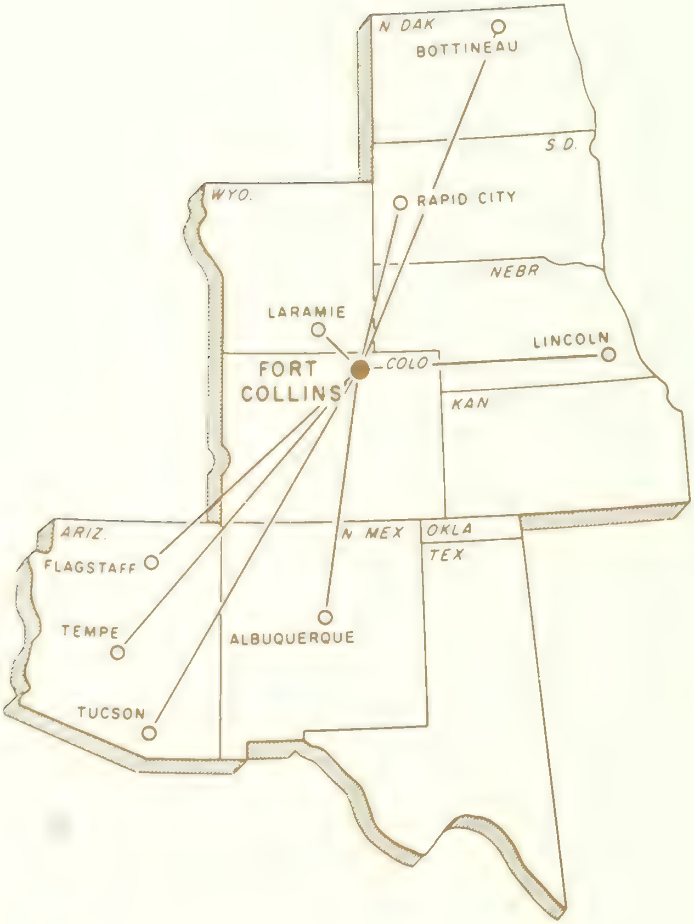
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RANGE MANAGEMENT IN THE CHAPARRAL TYPE AND ITS ECOLOGICAL BASIS:

The Status of Our Knowledge

Dwight R. Cable

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USDA Forest Service
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October 1975

Abstract

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1975. Range management in the chaparral type and its ecological basis: The status of our knowledge. USDA For. Serv. Res. Pap. RM-155, 30 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Chaparral in Arizona is used far below its potential. Conversions to grass can greatly increase water and grass production, and improve wildlife habitat. Management options include conversion to grass, maintaining shrubs in a sprout stage, changing shrub composition, reseeding, and using goats to harvest shrub forage.

Keywords: Chaparral, range management.

JSDA Forest Service
Research Paper RM-155

October 1975

RANGE MANAGEMENT IN THE CHAPARRAL TYPE AND ITS ECOLOGICAL BASIS:
The Status of Our Knowledge

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CONTENTS

Page

PHYSICAL CHARACTERISTICS OF THE CHAPARRAL TYPE 1
- Geographic 1
- Climatic 1
- Geologic and Edaphic 2

ECOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS OF THE BIOTA 3
- Systematics 3
  - Taxonomic 3
  - Communities 7
- Morphologic and Phenologic 7
  - Major Shrub Species 7
  - Litter Production 9
- Successional Pattern 9
  - Stages Represented 9
  - Present Condition 11

HISTORICAL DEVELOPMENT 13

RANGE MANAGEMENT PRACTICES 13
- Deciding Proper Grazing Use 13
  - Kind of Animal 13
  - Number of Animals 13
  - Season of Grazing 14
  - Grazing Systems 14
- Improving Forage Production 14
  - Seeding 14
  - Plant Control 15
  - Economic and Other Benefits of Conversion 20
  - Fertilizer Applications 20
- Increasing Usability of the Range 20
  - Water Development 20
  - Fencing 21
  - Salt Placement 21
  - Riding 21
  - Trail Construction 21
- Managing the Livestock 21
  - Nutrition 21
  - Protection 22
  - Operational Costs and Returns 22
- Correlating Grazing With Other Uses 22
  - Water 22
  - Wildlife 23

EMERGING DEMANDS FOR THE RESOURCE 24

SUMMARY AND EVALUATION 24

LITERATURE CITED 25

COMMON AND BOTANICAL NAMES OF PLANTS 29

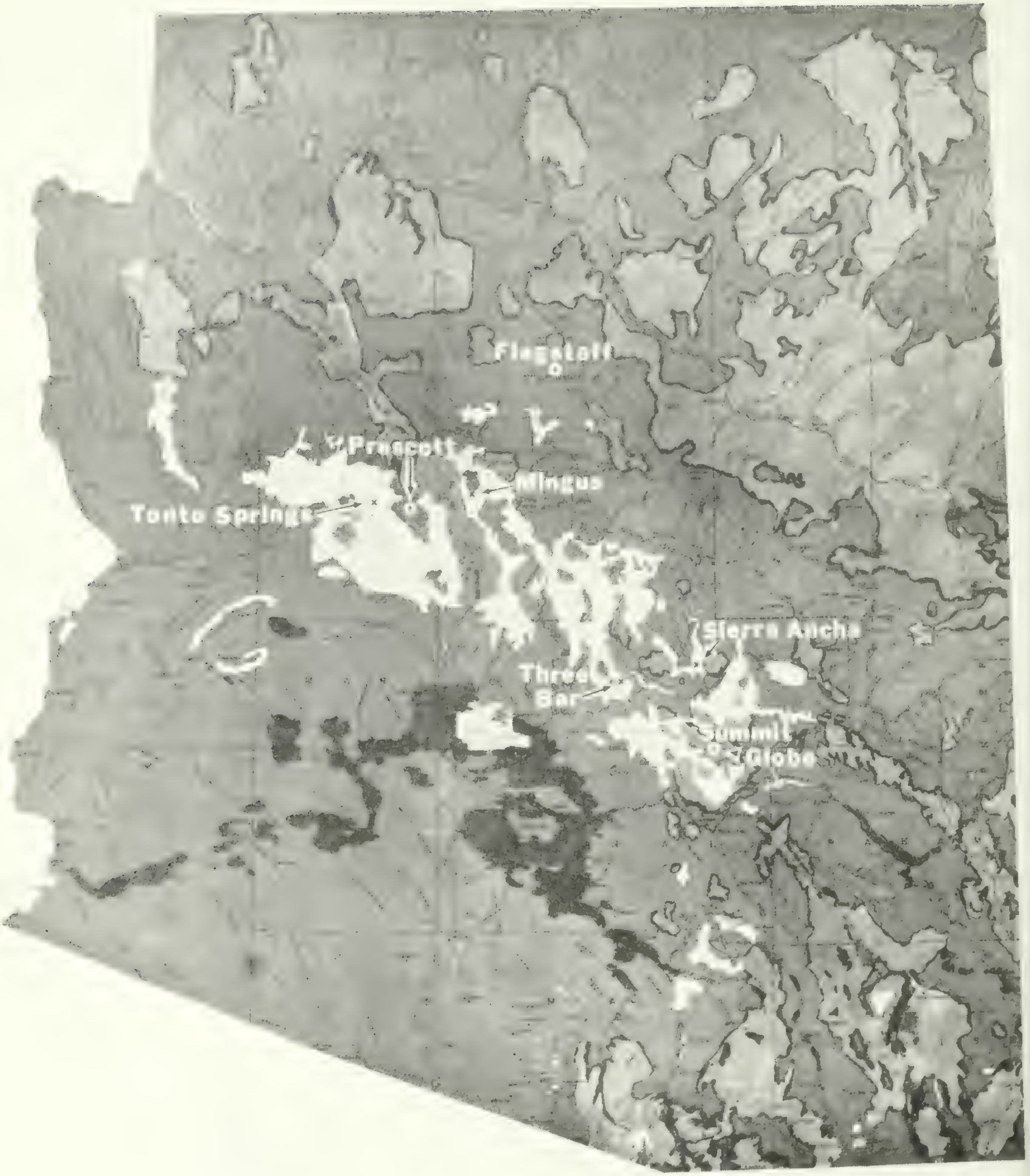

Figure 1.—Chaparral type in Arizona (in white), with locations of major experimental areas (adapted from Ariz. Agric. Exp. Stn. Bull. A-45).

RANGE MANAGEMENT IN THE CHAPARRAL TYPE AND ITS ECOLOGICAL BASIS:
The Status of Our Knowledge

PHYSICAL CHARACTERISTICS OF THE CHAPARRAL TYPE

Geographic

The chaparral type of the southern Rocky Mounains is located almost exclusively in Arizona, where t occupies a relatively narrow, discontinuous band f broken, rough terrain. This band extends in a outheast-to-northwest direction through the central art of the State, just south of the Mogollon Rim fig. 1).

←

The total acreage in the chaparral type has been eported variously between 4 million (Hibbert and ngebo 1971) and about 5.8 million acres (Nichol 952), apparently depending largely on where bounlaries are set as the type intergrades with more mesic nd xeric species at the upper and lower elevational oundaries, and with the intensiveness of type lelineations within the main body of the chaparral rea itself. Probably the most authoritative single nap of the chaparral type in Arizona was published y the Arizona Agricultural Experiment Station 1965), based on data from the USDA Forest ervice, USDI Bureau of Land Management, USDI ureau of Indian Affairs, USDA Soil Conservation ervice, and original mapping by R. R. Humphrey. dot-grid acreage determination of the chaparral ype as shown on this map indicates only about 3.2 nillion acres, probably a rather realistic figure.

Physiographically, the chaparral type occupies ortions of the Transition Zone, south of the Plateau rovince (which is bounded on the south by the ogollon Rim) and the Mountain Region of the asin and Range Province to the south (Wilson 962). Most of the central portion of the chaparral ype (eastern Yavapai and northwestern Gila counies) is in the Transition Zone, which structurally resembles the Plateau Province to the north in that its strata (predominantly sedimentary and volcanic rocks) for the most part lie essentially flat, only moderately affected by faulting and erosion. In most of the remainder of the chaparral type, the Mountain Region, the strata have been more intensely deformed by faulting, volcanism, erosion, and sedimentation.

Topography in the chaparral type consists largely of isolated mountain ranges cut by steep-walled canyons and gorges (Sellers 1960). The area is mostly drained by the Gila River and several of its tributaries (the Verde, Salt, Agua Fria, and Hassayampa). Flows of the Salt, Verde, and Gila Rivers are collected by the reservoirs within the general area. The westernmost portion of the chaparral type drains westward through the Bill Williams River directly into the Colorado River.

Elevations within the chaparral type vary mostly between 3,000 and 6,000 feet (Hibbert and Ingebo 1971), although the main mountain peaks rise to from 7,500 to 8,000 feet (Sellers 1960).

Climatic

Precipitation is concentrated largely in two distinct periods in the chaparral type, as in the rest of the State. This climatic aspect of Arizona's chaparral type differs markedly from that of the other major world chaparral communities, whose climates are characterized by wet, mild winters and long, hot, dry summers (Biswell 1954).

The summer rains fall primarily in July and August, the two wettest months of the year. The winter precipitation season extends from December through the middle of March. Average annual precipitation in the "central" section of Arizona (whose exterior boundaries agree very closely with those of the chaparral type) is 18.87 inches, of which an average of 48 percent falls between May and October (Sellers 1960). Annual precipitation ranges between about 15 and 25 or more inches. Average depth of snowfall varies within the type from about 4 to 25 inches per year.

Summer precipitation comes almost entirely from the Gulf of Mexico to the southeast, and falls in convective thunderstorms when the moist, tropical air flows over strongly heated mountainous terrain. In perhaps one year in five, a late August or September tropical hurricane off the west coast of Mexico will produce a deep surge of moist tropical air into the State from the southwest, yielding flood-producing rains.

Arizona's winter precipitation is associated with large-scale cyclonic storms originating over the Pacific Ocean, which are occasionally displaced southward from their normal eastward path. Because of the more complicated synoptic situations required to produce winter precipitation over Arizona, cool-season precipitation is considerably more variable from year to year than warm-season (Sellers 1960). The two precipitation seasons are separated by dry periods in spring and fall, the spring drought (May and June) being particularly severe.

Average daily maximum temperatures for the hottest months in the chaparral type (usually July) vary from about 88° to 98°F, with absolute maximums from 99° to 110°F (average daily minimums for the same month vary from 52° to 68°F). Average daily minimum temperatures for the coldest month (usually January) vary from 20° to 31°F, with absolute minimums from -21° to 1°F (average daily maximums for the same month vary from 50° to 57°F). Average temperatures in summer vary rather uniformly with elevation, decreasing about 1°F for each increase of 235 feet in elevation (Sellers 1960). Winter temperatures are not so closely correlated with elevation.

Geologic and Edaphic

All three major classes of rocks are represented in the parent material rocks of the chaparral type (Kearney and Peebles 1951, Schmutz and Whitham 1962, Pase and Pond 1964, Saunier 1964, Kemp 1965):

Igneous rocks: granites, basalt, diabase, granodiorite, quartz, diorite, gabbro, lavas.
Sedimentary rocks: shales, limestones, sandstones.
Metamorphic rocks: gneisses, schists, quartzite.

Sedimentary rocks predominate in the central portion of the chaparral type (Transition Zone); granite is a prevalent parent material over much of the rest of the type (Rich 1961).

Soils developed from granitic parent materials are mostly of sandy texture, relatively shallow, and low in fertility. Lava and basalt substrata, however, give rise to fine-textured soils (Saunier 1964) as also do shales, sandstones, and limestones at higher elevations (Pase and Pond 1964). Along the drainages deep alluvial sandy loams are common (Schmutz and Whitham 1962). Because chaparral shrubs require deep rooting for optimum development, the presence of such shrubs on shallow soils indicates deep fracturing and weathering of the parent material Shrub roots can obtain water that penetrates below the reach of most grasses and forbs (Saunier 1964 Pase and Fogel 1967, Suhr 1967, Hibbert and Ingebo 1971, Ingebo 1971).

The wide range in climatic, topographic, geologic and edaphic conditions within the area occupied by the chaparral type produces a variety of vegetation types: chaparral, oak woodland, pinyon-junipe woodland, and grassland. Their particular distribution undoubtedly depends in part on combinations o environmental factors that slightly favor (more near meet the physiological requirements of) one kind o vegetation over another. The precise limits of th environmental factors within which one type o vegetation is favored over another are not know However, some generalizations have been mad based largely on observation. McGinnies et al. (194 discussed this situation as it applies to the Arizo chaparral type as follows:

> Oak woodland is similar to chaparral in i requirements, but is usually found where moistu conditions are more favorable. The requiremen of pinyon-juniper woodland do not appear to be definitely set except that the major species successfully withstand much lower temperatures th those of the broadleaf woodland type.
>
> In many places in the Southwest these vegetation types are found growing under conditions ne the extremes of their tolerance. For examp chaparral will be found where the precipitation approximately equally divided between summ and winter. Grassland is also found under simi conditions, and in many places these two ty enter into direct competition. Under such conditions other factors may determine the ultim vegetational development. Usually on the coar more open soils, particularly on steep slop chaparral will be found, while on the heavy soi and more level ground grassland will domina but the increase or decrease in intensity of ot factors may tend to throw the vegetation eit towards brush or towards grass. Thus grazi which is more severe in its effect on grass, fav the invasion of chaparral even on heavier soils a where the climate is definitely more favora toward grass.

Erodibility of chaparral soils varies with the parent material from which the soils developed. Fletcher and Beutner (1941) reported that the "erodibility ntegral" (a rating based on "erosion-against-slope" curves) for central Arizona soils above 3,500- to 4,000-foot elevations is low for soils developed from quartzite, basalt, and limestone (EI = 3.7, 3.4, and 3.2, respectively), but is three times as high for soils developed from granite (EI = 9.9).

ECOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS OF THE BIOTA

Systematics

Taxonomic

Plants.—At least 50 shrub species have been reported in the chaparral type, although Pond and Bohning (1971) state that fewer than 15 are really mportant from either a density or animal-preference standpoint. Nichol (1952) reports that on many areas the stand is a heterogeneous association, but that more often one or two species dominate the type to give it a specific character. All authorities agree that shrub live oak[2] is the most abundant element of the chaparral (Kearney and Peebles 1951) (fig. 2). The diversity in stand composition has been ascribed to differences in soils, slopes, elevations, exposures, and precipitation (Nichol 1952, Pond 1964).

The upper and lower boundaries of the chaparral exhibit an intermixture of types. At the lower elevations, the chaparral may occur on north-facing slopes with desert shrubs on the south-facing slopes (Swank 1958, Rich 1961), or the chaparral may join with semidesert grassland (Pase 1966). In such situations shrub live oak is usually the dominant, with small amounts of skunkbush sumac, catclaw acacia, catclaw mimosa, nolina, sugar sumac, or California

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[2] *Common and botanical names of plants mentioned are listed at the end of this Paper.*

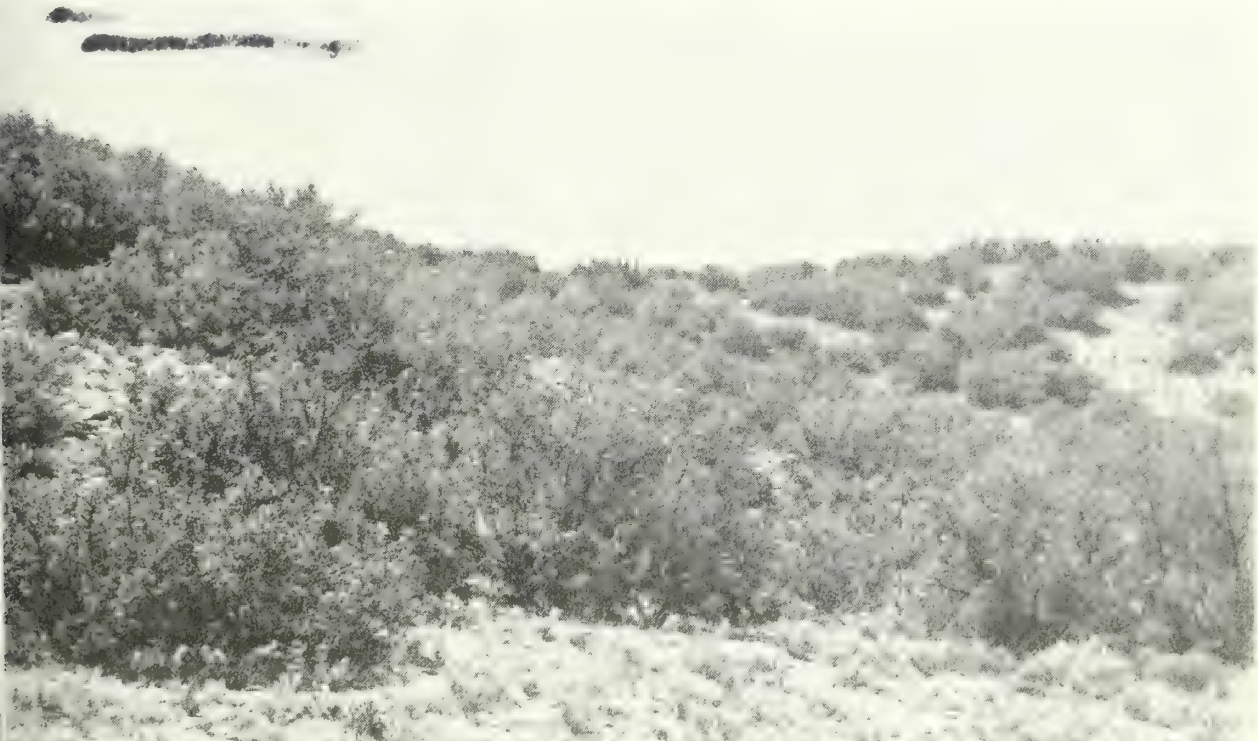

Figure 2.—Chaparral type at approximately 5,000 feet elevation southwest of Prescott; predominantly shrub live oak; loose granitic soil; annual precipitation about 17 inches.

jojoba, and often occasional semidesert shrub species (Swank 1958, Rich 1961, Pase and Johnson 1968) (fig. 3). At the upper boundaries, the chaparral frequently extends as an understory into the fringes of the ponderosa pine or pinyon-juniper types. In these situations species such as true mountain-mahogany, Emory oak, Arizona white oak, Wright silktassel, deerbrush, Pringle manzanita, and one-seed juniper may be associated with the dominant shrub live oak (Nichol 1952, Swank 1958, Pase 1966, Pase and Johnson 1968) (fig. 4).

Within the midportion of the type, differences in shrub composition on north and south exposures may indicate relative preferences of the various

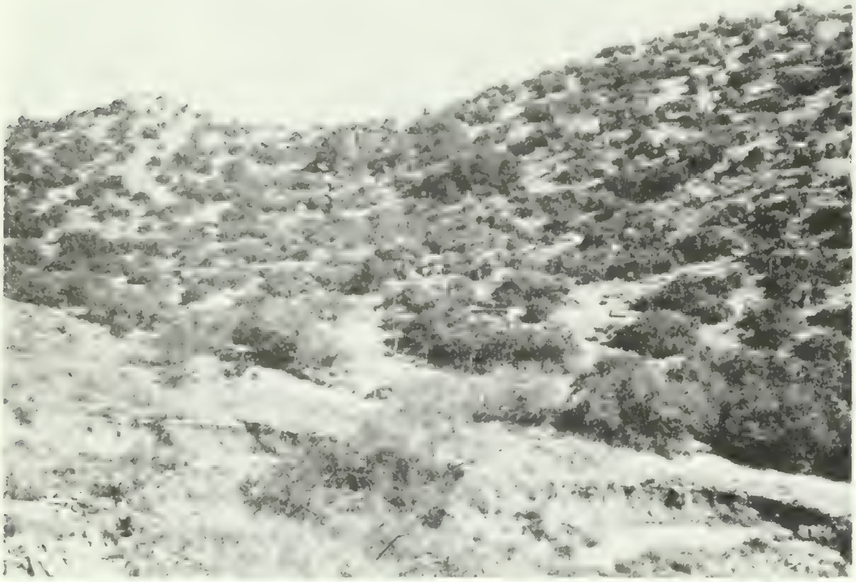

Figure 3.—Low-elevation (3,800 feet) chaparral on north slope at Summit watersheds, Tonto National Forest; loose granitic soil; annual precipitation about 15 inches [redacted]

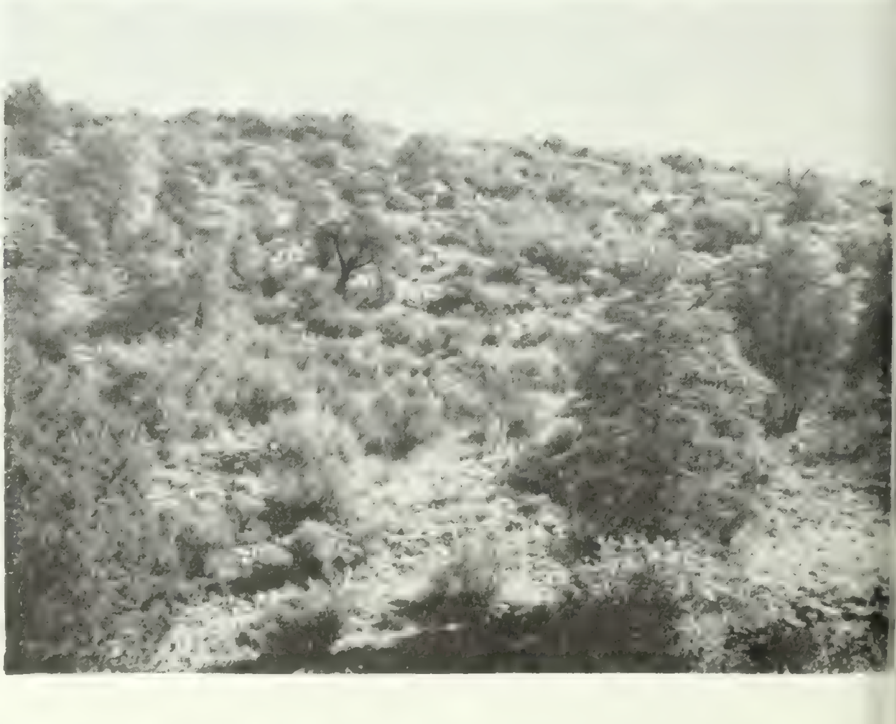

Figure 4.—High-elevation chaparral on Tonto National Forest with scattered Emory oak. Understory grasses are primarily side-oats and hairy gramas, and curly mesquite.

pecies for more mesic or xeric conditions, respecively. Kemp (1965) provides such a comparison for wo areas on the Sierra Ancha Experimental Forest t about 5,000 feet elevation and 23 to 25 inches nnual precipitation. Slopes averaged between 30 nd 50 percent. Species preferring the south exosure were catclaw acacia, pointleaf manzanita, nd nolina. Those preferring the north exposure were kunkbush sumac, hollyleaf buckthorn, Arizona vhite oak, pinyon pine, and to a lesser extent, true nountainmahogany, and desert ceanothus. Shrub ve oak and Wright silktassel were equally abundant n both exposures.

Soil type preferences have not received much nvestigation, although one-seed and Utah junipers nd cliffrose are reported to be particularly abundant n soils derived primarily from limestone near the pper transition (Swank 1958). Darrow (1944) notes hat pointleaf manzanita occurs most frequently on ranitic soils, and that hairy mountainmahogany ften comprises pure stands on limestone slopes bove 5,000 feet elevation in Chochise county. Soil ifferences are also reported as responsible for the eparation of chaparral and juniper under otherwise imilar environmental conditions, with chaparral ccupying coarse-textured soils derived mainly from ranite, and juniper occupying fine-textured soils erived from basalt, limestone, and quartzite (Hibert et al. 1974).

Composition reported for specific shrub stands ndicates that (1) shrub live oak comprises from 45 to 0 percent of the total shrub cover on most sites, (2) isually only one or two other shrub species conribute over 10 percent of the total shrub cover, (3) etween 7 and 10 individual shrub species are resent on any given area, and (4) total shrub crown aries between about 25 percent at lower elevations vith lower precipitation, and 80 percent, at higher levations with higher precipitation. In view of the iterature references to true mountainmahogany as avoring the higher elevations of the chaparral type, ts relative abundance on several areas in table 1, ven at the Summit watershed at 3,700 feet elevation nd 15 inches annual precipitation, is somewhat nexpected.

A detailed listing of plant species in the chaparral ype on the Sierra Ancha Experimental Forest ncluded 37 species of trees and shrubs, of which our were listed as "very abundant" (Pase and ohnson 1968). Also listed were 139 forbs and 30 rasses.

Few understory forbs and grasses are present at he upper elevations of the chaparral type at Sierra ncha where shrub crown cover is high. At the lower levations, however, where shrubs are more scatered, understory grasses and forbs are fairly comnon, especially annuals (Pase and Johnson 1968). carcity of understory plants in denser chaparral stands in other parts of the type has also been noted by Saunier (1964), Pase and Ingebo (1965), Pase (1966), and Ingebo (1971).

Tiedemann and Schmutz (1966) report from 3 to 8 percent ground cover of forbs on chaparral areas east of Prescott (purslane was the dominant) and from 0 to 2 percent ground cover of grasses, primarily Lehmann lovegrass and side-oats grama. Broom snakeweed was the dominant half-shrub, with lesser amounts of Wright eriogonum and toadflax penstemon (total half-shrub densities 2 to 5 percent).

Black, hairy, and side-oats gramas and threeawns may dominate the herbaceous cover at lower elevations where chaparral borders on semidesert grasslands (Pase 1966). Swank (1958) notes that side-oats grama is particularly abundant at the higher elevations where the chaparral intergrades with pine forest or juniper-grassland types. He also notes that red brome (= foxtail brome, an annual grass) is the most abundant herbaceous species at lower elevations in the Three-Bar area, with spurges and threeawns also common, and that on heavily grazed chaparral areas broom snakeweed often forms a nearly pure understory.

In the southeastern part of the type (Cochise county), Darrow (1944) notes that bullgrass, deergrass, little bluestem, side-oats grama, and plains lovegrass are common in the chaparral above 5,000 feet, and side-oats and hairy gramas, bluestem, and green sprangletop are common at the lower elevations.

At Tonto Springs, west of Prescott (5,000 feet elevation) common half-shrubs were broom snakeweed and Wright eriogonum, and common perennial grasses included blue, black, hairy, and side-oats gramas, several threeawns, squirreltail, and longtongue mutton bluegrass (Pond 1968c).

Animals.—The principal game animal in the chaparral type is the mule deer, although peccaries are common at lower elevations. Gambel quail are also common at lower elevations (Rich and Reynolds 1963). Coyotes, bobcats, badgers, foxes, and skunks also inhabit the type, depending on the availability of small rodents for food, and whitetail deer are common in the higher areas (Nichol 1952, McCulloch and Urness 1973). The chaparral is also an important type for the black bear. Densities of mule deer are estimated to vary from 4 to 5 per square mile in stands of shrub live oak and skunkbush sumac to 20 to 30 per square mile at higher elevations where birchleaf mountainmahogany, desert ceanothus, and hollyleaf buckthorn are abundant (Swank 1958).

A detailed listing of vertebrates in the chaparral type on the Sierra Ancha Experimental Forest includes 83 species, broken down as follows (Reynolds and Johnson 1964):

Table 1.--Elevation, precipitation, and percent composition of shrub crown cover at several undisturbed locations[1] in the chaparral type

Elevation, precipitation, and shrub species	Sierra Ancha Experimental Forest			Three Bar watersheds		Copper Creek	Bloody Basin	Summit watersheds	Southern Mingus Mountain area, east of Prescott			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Feet											
Elevation	4700	4900	5100	4500	3500	4000	3600	3700	----4900 to 5350----			
	Inches											
Annual precipitation	21	23	25	23	26	17	15	15	15	15	15	15
	Percent											
Shrubs:												
Shrub live oak	72	53	49	45	26	60	42	59	60	80	75	67
Pointleaf manzanita	--[2]	1	25	--	--	--	--	--	6	T	5	7
Hairy mountainmahogany	--	--	--	--	--	--	--	--	6	1	4	1
True mountainmahogany	T	13	8	22	--	10	--	31	--	--	--	--
Desert ceanothus	14	8	3	1	--	4	--	--	1	2	1	1
Hollyleaf buckthorn	7	6	1	9	--	1	--	--	--	T	--	--
Wright silktassel	1	9	8	1	--	--	--	--	--	--	--	--
Skunkbush sumac	6	7	T	1	--	20	--	--	24	14	16	22
Sugar sumac	--	--	--	4	--	1	--	--	--	--	--	--
Catclaw acacia	T	1	1	11	4	42	--	--	--	--	--	--
Palmer oak	--	--	--	16	--	--	--	--	--	--	--	--
Nolina	--	1	5	--	--	--	--	--	--	--	--	--
California jojoba	--	--	--	--	26	--	--	--	--	--	--	--
Pinyon pine	--	T	--	--	--	--	--	--	--	--	--	--
Arizona white oak	--	2	--	--	--	--	--	--	--	--	--	--
Jumping cholla	--	--	--	--	16	--	--	--	--	--	--	--
Datil yucca	--	--	--	--	5	--	--	2	--	--	--	--
Palo verde	--	--	--	--	11	--	--	--	--	--	--	--
Velvet mesquite	--	--	--	--	5	--	--	--	--	--	--	--
Mescat acacia	--	--	--	--	--	--	--	8	--	--	--	--
Others	--	--	--	--	--	--	14	--	--	--	--	--
Total crown cover	57	81	82	70	--	50	12	25	36	37	36	28

[1] Locations and authors of reports:
(1) -Natural Drainages (unpublished data 1956)
(2,3)-(Unpublished data 1965)
(4) -NW of Roosevelt Reservoir (unpublished data 1956)
(5) -(Swank 1958)
(6) -NW corner of Tonto NF (Swank 1958)
(7) -SE Yavapai County (Swank 1958)
(8) -North of Globe (Rich 1961)
(9,10,11,12) -(Tiedemann and Schmutz 1966)

[2] "--" indicates negligible.

Species	Total observed	Common occurrence
	(*Number*)	
Lizards (including Gila monster)	12	6
Snakes (including 2 rattlesnakes)	10	6
Birds	42	29
Bats	6	4
Rodents	5	4
Carnivores	6	2
Even-toed ungulates	2	2
	83	53

The carnivores are coyote, fox, black bear, ring-ail cat, and two species of skunks. The even-toed ungulates are the collared peccary and whitetail deer.

Communities

The literature makes little mention of communities in the chaparral type. One probable reason for so ittle work having been done on this phase of chaparral ecology is that only a few species of shrubs are capable of dominating the cover over any sizable area. Swank (1958) took a step in the direction of community delineation by recognizing: (a) a shrub live oak-skunkbush sumac type in the drier portions of the chaparral, (b) a mixed shrub type to include most other combinations of shrub live oak and other species, and (c) nearly pure stands of manzanita or mountainmahogany. Manzanita in particular forms dense thickets of relatively large extent in certain areas of the chaparral (Nichol 1952). Darrow (1944) divided the chaparral and mountain browse type of Cochise county into four segments: (a) nolina, (b) mountainmahogany, (c) desert ceanothus, and (d) mixed shrubs.

It should be noted that, while the Arizona chaparral resembles the California chaparral in general character as a broad sclerophyll shrub community, and shares some of the same species, the major dominants (as well as the characteristic climates) are different (McGinnies 1972).

Lack of knowledge of how the characteristics of the various chaparral communities are related to productive potentials for range, wildlife, watershed, and recreation purposes seriously restricts the ability of land managers to plan action programs to achieve the improvements that are possible. Obtaining the basic information necessary for making these decisions should have high priority in any future research program in the chaparral type.

Morphologic and Phenologic

The Arizona chaparral type consists almost entirely of broad sclerophyll shrub communities, mostly of low-growing species with thick, evergreen leaves. The leaves of most species remain on the plants throughout the winter and until new leaves are well developed the following spring (Pond and Bohning 1971). Skunkbush sumac is an exception; its leaves are not thick and leathery, and are dropped following the first fall frosts.

Chaparral shrubs normally produce most of their growth in the spring. Summer growth is dependent on sufficient rain to recharge the soil water, and is thus spotty and not dependable (Swank 1958). Swank felt that available water was the primary factor controlling growth of chaparral shrubs, because the presence of leaves throughout the year permits photosynthesis almost whenever soil moisture is available. Reynolds (1967), however, reported that temperature appeared to control the beginning and ending of the growth period for shrub live oak, Wright silktassel, and mountainmahogany. Growth occurred when average daily temperatures were between 50° and 80°F (April to November). These observations suggest that growth periods are probably controlled by the interaction between temperature and soil moisture.

Major Shrub Species

Characteristics of the major shrub species are described by Dayton (1931), USDA-FS (1937), Swank (1958), and Pond and Bohning (1971) as follows:

Shrub live oak.—The most abundant shrub in the chaparral, this species usually grows 3 to 8 feet tall, but can grow to 15 feet with basal stems over 4 inches in diameter. It usually grows in clumps, often with thousands of individual stems from a single or more often several separate root crowns. A drought-resistant species, it grows from as low as 2,000 feet elevation to as high as 8,000 feet, but mostly between 4,500 and 6,000 feet. Root crowns contain thousands of inactive buds which can sprout following fire, or chemical or mechanical treatments that destroy the aboveground parts of the plant. Plants are long lived. Of eight plants tagged and photographed in 1920 on the Sierra Ancha Experimental Forest, only one died during the next 47 years (Pond 1971).

Because of the long-lived nature of shrub live oak, its vigorous sprouting capabilities, and its high natural resistance to damage by browsing, pests, and disease, few seedlings are needed to maintain a healthy stand. Seedlings are seldom found under natural conditions in most years. In favorable years, seeds germinate and become established from late July to mid-September. Excavations of 3-year-old seedlings at Sierra Ancha (Pase 1969) showed that the plants averaged 2.9 inches tall, but roots had reached a depth of 21 inches. From examination of precipitation records, Pase hypothesized that successful oak seedling germination and establishment requires 15 inches or more of October-March precipitation followed by 10 inches or more of July-September rainfall. Precipitation records indicate that these requirements are met on the average of only 1 year in 10 at Sierra Ancha.

Although low in palatability, shrub live oak is an important source of forage for livestock and deer because of its abundance and its availability for emergency use during winters of heavy snow when other feed may be scarce. New succulent growth is readily grazed. Goats graze shrub live oak at all seasons. The acorns are relished by deer, wild turkey, and possibly by other wild game.

Mountainmahogany.—Three species of mountainmahogany grow in various parts of the Arizona chaparral. True mountainmahogany has the widest range, from South Dakota and Montana to New Mexico and Arizona. In Arizona, it prefers elevations from 4,500 to 7,000 feet. Birchleaf mountainmahogany is found in Arizona on the lower warmer slopes, from 3,000 to 6,500 feet, mostly in the chaparral. Hairy mountainmahogany has the most restricted range, western Texas to Arizona, and is found at higher elevations, 5,000 to 8,000 feet on dry slopes and mesas in the chaparral type. These species ordinarily grow to about 10 feet tall, but birchleaf and true mountainmahogany can reach 20 feet and hairy mountainmahogany 15 feet. These shrubs seldom form pure stands, but may dominate localized areas. They all sprout from root crowns following fire. They are important forage species for livestock and deer, and withstand heavy browsing very well, although in certain locations the palatabilities have been reported to be low.

Desert ceanothus.—Desert ceanothus ranges throughout the chaparral type, from 3,000 to 7,000 feet elevation, but more commonly at the lower elevations, and always in association with other species. It seldom exceeds 6 feet in height, and is relatively short lived. Desert ceanothus seldom sprouts after fire, but it produces seed every year from which new plants eventually become established. Although it is not as palatable for cattle as some other species, Swank (1958) rates it "at the top of the list of preferred foods" for deer. Unfortunately, it cannot withstand continuous heavy browsing, and is eventually eliminated on areas with large deer populations.

Manzanita.—Two species of manzanita are common in the Arizona chaparral—pointleaf and Pringle. Pringle manzanita is somewhat larger but less common than pointleaf. Pringle manzanita grows to about 6 feet tall, in large clumps which often grow so close together that they form nearly pure impenetrable thickets several hundred acres in extent. These species seldom sprout, but they can form new plants by layering wherever a stem touches the ground. Seeds are fire scarified, and seedlings quickly reoccupy burned areas. Manzanitas are practically worthless as forage for cattle and deer, although goats are reported to graze them freely, and the berries are used by bear and birds.

Skunkbush sumac.—Skunkbush sumac is the one common chaparral shrub that loses its leaves every fall. It is common throughout the type from 2,500 to 7,500 feet elevation, but seldom forms more than a few percent of the overstory. This plant grows to 7 feet tall, but averages about 4 feet. It sprouts vigorously from the root crown following fires. The plant is relatively long lived. The forage value of skunkbush sumac for livestock and deer is definitely low, in both palatability and nutritive value, although Chapline (1919) reports it to be of very high palatability for goats.

Hollyleaf buckthorn.—This shrub is common in the chaparral from 3,000 to 7,000 feet elevation, always in association with other shrubs. This species sprouts vigorously from the root crown after fire, grows rapidly, and is grazed readily by both cattle and deer. It withstands heavy use quite well, in part because it is able to grow beyond the reach of both cattle and deer.

Wright silktassel.—Wright silktassel, one of the taller chaparral shrubs (to 10 feet), is common throughout the type but most abundant from 5,000 to 8,000 feet. It varies from absent to locally very abundant. It sprouts rapidly from the root crown following fire, and grows vigorously. Swank (1958 reports that deer browse silktassel moderately, and that livestock prefer it to many other species Chapline (1919) rates it moderately high in palatability for goats.

Cliffrose.—Cliffrose is found in the chaparral typ and higher, between 3,000 and 8,000 feet, but it i most abundant at the higher elevations. It seems t prefer limestone-derived soils, but is also found o granitic, volcanic, and other igneous formations. It i a long-lived plant and ordinarily grows to a max mum of about 12 feet tall, but in the most favorabl situations may reach 25 feet. Cliffrose is an important and valuable browse plant for sheep, cattle, an deer, particularly in winter; it is little used in sprin and summer if other succulent forage is available.

Sugar sumac.—Also known as mountain laurel, this large shrub (to 15 feet tall) is found throughout the chaparral, but most abundantly between 3,000 and 5,000 feet elevation. It may become locally abundant, but usually occurs as scattered individuals. Pase and Johnson (1968) list it as occasional in the chaparral type at Sierra Ancha. Sugar sumac sprouts vigorously from the root crowns after fire, and the young sprouts are used heavily by deer. Mature growth is seldom used by deer or cattle.

Catclaw mimosa.—Catclaw mimosa (also called wait-a-bit) is a deciduous shrub of the semidesert shrub type and the lower parts of the chaparral type from 3,000 to 6,000 feet elevation, frequently in large dense thickets. It is relatively short, usually not more than 3 feet, but occasionally to 6 or 8 feet tall, and densely prickly with paired catclawlike prickles at the nodes on all stems. In its prickliness and deciduous character, catclaw mimosa is more semidesertlike than chaparrallike. This species sprouts profusely after fire. The younger, less prickly growth is sometimes grazed, and the pods are well liked by cattle, but the species is of strictly minor importance as forage for livestock and deer in the chaparral type.

Emory oak.—Emory oak grows as a shrub or small tree (to 50 feet tall under optimum conditions) on deep soils in the chaparral type. It also extends downward along watercourses to the uppermost edge of the desert and desert grassland (Benson and Darrow 1944) and upward into the oak woodland, from 3,000 to 8,000 feet elevation. On drier sites it occurs as scattered individuals of shrub size; on deeper soil and more mesic sites it may occur as groves of small to medium trees (Pase 1969). Emory oak sprouts and grows vigorously from the root crown following fire. Livestock and deer make little use of this species for forage (Swank 1958).

Litter Production

At Sierra Ancha, three-fourths of the litterfall from shrub live oak accumulates from April through August. About 90 percent of the litter consisted of leaves; catkins, twigs, bark, and acorns made up the remainder (Pase 1972). Litter was shed rather uniformly (10 to 15 percent per month) on north slopes during the 5 months, but on south slopes 47 percent of the litter fell during April and May. December and January were the lowest yielding months on both exposures. For the chaparral community as a whole, the peak litterfall was during summer (44 percent of the annual total), followed by winter and spring (20 percent each), and fall (16 percent).

Litter yield from shrub live oak is high, relative to its crown cover, while litter yield from pointleaf manzanita, skunkbush sumac, and desert ceanothus is low (Kemp 1965). The total weight of the forest floor under nine caged shrub live oaks averaged 8,200 pounds per acre for the north exposure and 14,600 pounds per acre on the south exposure. The depth of the forest floors averaged slightly over 1 inch (Pase 1972), representing between 5 and 10 years' accumulation of annual litter. The lower weights on the north slope are probably an indication of a considerably higher rate of decomposition due to the more mesic conditions.

More dense stands (85 to 95 percent canopy cover) of shrub live oak and Pringle manzanita at Sierra Ancha, and of manzanita alone in the Mazatzal Mountains, showed total forest floor weights of 24,200 and 22,400 pounds per acre, respectively (Garcia and Pase 1967). A dense, mature, nearly pure stand of Pringle manzanita in central Arizona yielded 41,277 pounds of litter per acre, with an average depth of 1.4 inches (Glendening and Pase 1964). These heavier weights are probably the result of heavier annual yields from the more dense stands, and much slower decomposition.

Research is needed to determine the variability in the amount and distribution of litter in the chaparral type and its effect on erosion rates.

Successional Pattern

According to Darrow (1961) the present-day chaparral type in Arizona apparently had its beginnings during the Miocene Epoch of the Tertiary Period of the Cenozoic Era. It was a Madro-Tertiary Flora of semiarid woodland and thorn scrub vegetation, which in late Miocene and early Pliocene times extended from California to Oklahoma and Texas. As the climate differentiated during this period, in response to continued uplift and orogeny in the southern Rocky Mountains and westward, the vegetation segregated itself also, and by mid-Pliocene times the formerly continuous chaparral belt had divided into a California segment and a Southwestern segment. The Arizona chaparral type is about all that remains of the Southwestern segment, and it apparently has been here for several million years—obviously a climax formation. Clements (1928) stated that "the chaparral formation constitutes a real climax, though portions of it are undoubtedly subclimax."

Stages Represented

Examples of chaparral extending beyond its normal climatic limits into pine or woodland types due to periodic burning, or into grassland due to prolonged heavy grazing by cattle, are properly referred to as subclimaxes (Clements 1936, Weaver and Clements 1938). Saunier (1964) concluded that, rather than representing past or present invasions, the small islands of shrub live oak surrounded by grassland common in the vicinity of Prescott and also at Sierra Ancha represent relicts of a formerly continuous stand. A combination of drought, fire, and somewhat less favorable soil moisture conditions has eliminated the oaks from the intervening spaces.

Fires, both natural and man-caused, burn periodically in the Arizona chaparral. However, Pase (1972) described one chaparral area that had not burned for at least 74 years. Baldwin[3] estimates the ages of some chaparral stands (since the last fire) at 80 to 100 years. He also estimates that burned chaparral areas left to recover naturally will not support a repeat burn for at least 20 years. If the burned area is reseeded to grasses, however, and a good stand is established, the area can burn again in 4 or 5 years. If 6 or 7 years elapse, the recovering shrub stand will have eliminated most of the grasses and another 15 or 20 years may pass before the area will support another fire.

It thus appears likely that little true chaparral climax remains, and that essentially the entire type has been burned over periodically. The type is not a fire climax, however, in the sense that fire is necessary to maintain it. The chaparral is a true climatic climax, but unusually susceptible to large-scale burning.

A single fire causes little retrogression in the chaparral climax because most of the dominant shrub species sprout readily from the root crown, and those that do not usually produce abundant seed that are stimulated to sprout by the fire. Thus, the chaparral stands tend to recover relatively rapidly following fire. There may be some changes in total shrub cover and in relative crown cover due to differences in the rapidity with which the various species sprout, and to the relative advantage of the sprouters over the nonsprouters in reoccupying the area. The density and composition of the understory is often changed also, with the advantage to the shrubs (Schmutz and Whitham 1962).

Crown cover generally recovers most rapidly during the first 3 years (up to 10 percent per year), gradually slowing as the cover approaches preburn levels (table 2) (Pase and Pond 1964). More than 11 years are required for the shrub cover to reach preburn levels (Hibbert et al. 1974) (fig. 5). Rates of recovery of individual shrub species vary with their inherent sprouting ability or seedling establishment ability, with their relative abundance in the preburn stand, and possibly with the time of year of the fire. Because of the competitive advantage of sprouts over seedlings, the relative crown covers of the strong sprouting species generally increase and that of the weak or nonsprouters decreases following fire, sometimes drastically.

The forb stage in the secondary succession after fire reaches a peak in the second or third growing

Table 2.--Percent composition of chaparral on Mingus Mountain, based on line intercepts, following June 1956 burn (Pase and Pond 1964)

Species	1956	1957	1958	1960	1961
	- - - -	- - - -	*Percent*	- - - -	- - - -
Shrub live oak	81.0	80.4	69.4	70.5	68.0
Skunkbush sumac	11.3	12.9	14.8	9.2	9.0
Catclaw mimosa	5.7	2.7	3.2	2.2	2.4
Broom snakeweed	0	T	7.2	11.5	11.8
Hairy mountain-mahogany	.4	1.4	2.1	1.6	2.3
Desert ceanothus	T	T	.4	1.4	1.8
Manzanita:					
Pringle	0	0	.4	1.6	2.0
Pointleaf	0	.1	.2	.2	.4
Others	1.5	2.6	2.4	1.8	2.4
Total	100.0	100.0	100.0	100.0	100.0
Shrub cover	4.8	16.2	28.6	37.6	41.7

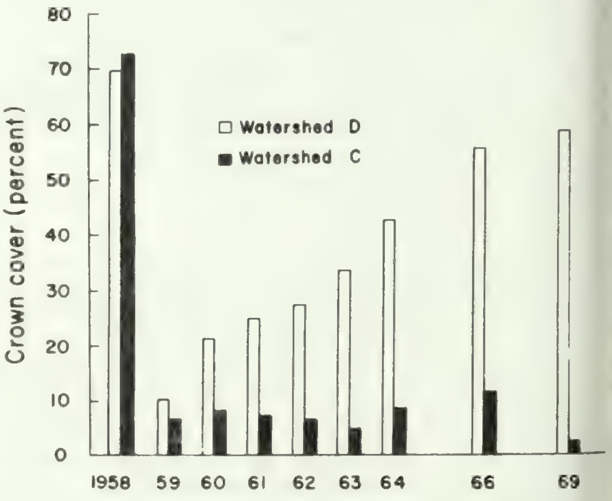

Figure 5.—Shrub recovery at Three Bar watersheds following 1959 wild fire: Natural recovery on watershed D; shrub sprouts suppressed with herbicides on watershed C (from Hibbert et al. 1974).

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[3] *Personal communication with Mr. Joy Baldwin, Fire Control Officer, Tonto National Forest, Phoenix, Arizona.*

season and then declines rapidly (table 3) (Pase and Pond 1964). Grasses are only slightly more permanent, usually reaching their peak in the fifth to the seventh year. The decrease in herbaceous understory after fire is attributed to increasing competition from the rapid shrub sprout and seedling growth, probably aggravated by increased grazing pressure on the remaining herbaceous plants as their abundance declines. (See also Swank 1958, Glendening et al. 1961, Hibbert 1971.)

Table 3.--Production of grasses and forbs on Mingus Mountain, upper and lower areas, burned in June 1956 (Pase and Pond 1964)

Area	1956	1957	1958	1960	1961
			- - - *Pounds/acre* - - -		
Upper area:					
Grasses	4	16	141	196	157
Forbs	T	22	259	127	22
Total	4	38	400	323	179
Lower area:					
Grasses	T	40	57	56	97
Forbs	0	15	28	31	8
Total	T	55	85	87	105

A comparison of seedling numbers 1 year after a planned October burn in the Mazatzal Mountains gives some indication of the relative seedling-producing ability of several common chaparral species (Pase 1965). Although the area burned was a dense manzanita community with a nearly "closed" canopy and only minor amounts of shrub live oak and desert ceanothus, seedlings of several species appeared on the burned area. Narrowleaf yerba-santa, Pringle manzanita, and desert ceanothus produced the largest numbers of seedlings, but five other species also appeared (table 4). The appearance of yerba-santa was completely unexpected, because it was totally absent from the mature stand; the seedlings apparently came from seed stored in the soil, perhaps for many years. Seedling appearance of all species was strongly (for most species, totally) dependent on the fire, and for most species a higher intensity of burn resulted in greatly increased numbers of seedlings compared to a light burn. On the unburned check area, only yellowleaf silktassel and Emory oak produced seedlings, but in fewer numbers than on the burned area.

Table 4.--Surviving 1-year-old seedlings (plants per acre) on El Oso Burn (Pase 1965)

Species	Burned October 1962		Unburned check
	Intense burn	Light burn	
	- - [illegible] - -		
Pringle manzanita	18,180	4,363	0
Desert ceanothus	2,618	636	0
Deerbrush	190	0	0
True mountainmahogany	95	0	0
Narrowleaf yerba-santa	101,293	16,453	0
Yellowleaf silktassel	571	1,182	59
Emory oak	143	364	118
Shrub live oak	48	91	0

Present Condition

Guides for evaluating the condition of Arizona chaparral ranges for livestock grazing have been developed by Rigden and Parker (1943), and Humphrey (1964). The main consideration in these guides is the relative abundance and productivity of desirable perennial grasses in the openings. Additional factors considered include the density of the shrub stand, presence of palatable shrubs, evidence of active erosion, and indicators of heavy grazing (fig. 6).

In terms of productivity for range livestock, the condition of much of the chaparral is not good. Even in 1941, McGinnies et al. noted that ". . . within the last 30 years fire and too heavy grazing have greatly increased the density (of shrubs) and encouraged encroachment of this type into adjacent types . . ."; and ". . . perennial grasses . . . were at one time more abundant than at present," especially blue, black, hairy, and side-oats gramas, dropseeds, three-awns, curly mesquite, bluestems, and wolftail.

Nichol (1952) stated that "Unless much broken by sod patches of considerable extent the type as a whole is poor range land." Rigden and Parker (1943) observed "There is much evidence that snakeweed as well as the larger shrubs has increased in density since the advent of grazing, whereas the herbaceous ground cover has become badly depleted over much of the type." Pond[4] noted that the perennial grass cover in the chaparral type was generally sparse, as reflected by the stocking rates of from 2 to 15 animals per section yearlong on the Tonto and Prescott National Forests.

Some isolated tracts of chaparral in the southeastern part of the State, on the other hand, appear to be in better condition. Humphrey (1960) noted that the chaparral type in the mountain foothills of the southeastern part of the State "usually grows

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[4] *Pond, Floyd W. 1962. Range management research in the Arizona-New Mexico chaparral—a project analysis and working plan. (Typewritten report on file at Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)*

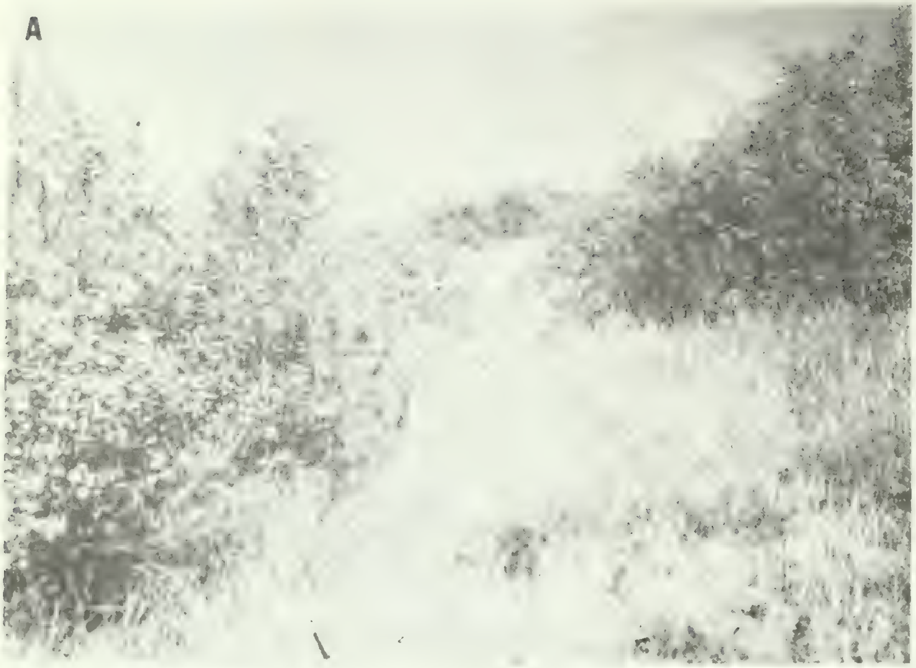
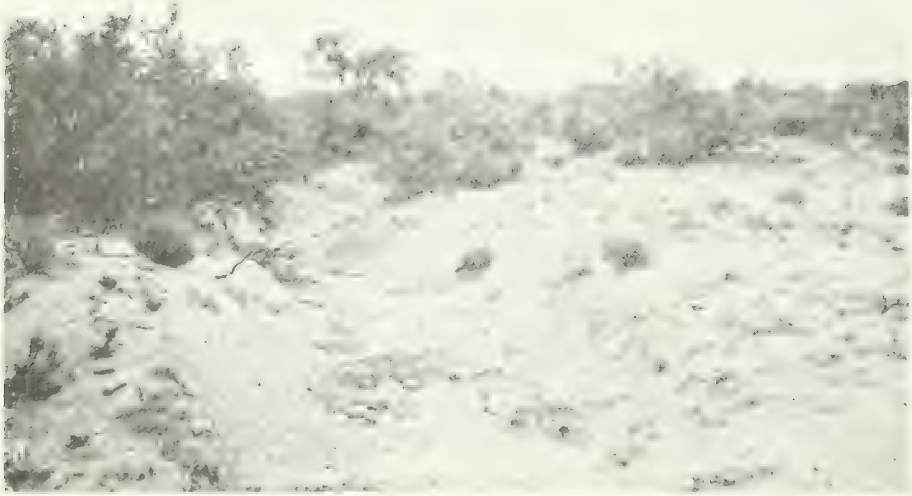


Figure 6.—
A, Chaparral range in excellent condition. High density and production of understory grasses, primarily side-oats and hairy gramas and curly mesquite.



B, Chaparral in poor condition. Herbaceous understory sparse and erosion active.

more grass and, consequently, produces more forage than it does farther north in the State" possibly due to regional differences in rainfall distribution.

Guides for evaluating chaparral areas for wildlife habitat, recreational use, and water yield potential are not available, and should be developed.

HISTORICAL DEVELOPMENT

Settlement of the chaparral area lagged some years behind that of the areas to the north and south because of the very rough topography. During the 1860's prospectors and traders accompanied Government troops on scouting trips within the chaparral type (Croxen 1926). During this period, several military posts were established within the type to prevent raids by the numerous Indian tribes that inhabited most of the territory (Lockwood 1932).

Prospecting and mining led to the earliest settlements within the chaparral type, such as Prescott, established in 1863, and Globe in 1873 (Barnes 1935). As reports of large areas of nutritious grasses spread outside the territory, settlers began bringing in livestock. In 1874 the first cattle were brought to the Tonto Basin country a few miles southeast of Payson. Within the next 10 years or so most of the type was stocked, primarily with cattle, but with a few bands of sheep and some goats (Croxen 1926). At this time, apparently, the shrub stands were quite open, with excellent stands of grass interspersed.

The Tonto Forest range was fully stocked with livestock by about 1890, but the peak stocking was not reached until about 1900. At this time there were 15 to 20 times as many cattle on the range as were present in 1926 (Croxen 1926), when stocking rates were presumably nearer true carrying capacity. One of the principal reasons for the drastic decline in stocking was an 18-month drought in 1903-04, which resulted in severe death loss on the overstocked and depleted ranges. By 1926 many of the areas that had been covered with stirrup-high grass stands 50 years earlier were dense stands of brush.

RANGE MANAGEMENT PRACTICES

Deciding Proper Grazing Use

Kind of Animal

The Arizona chaparral is now grazed almost exclusively by cattle. However, experience in other parts of this country and in other countries strongly suggests that goats or goats and cattle would produce greater returns in meat and other products than cattle alone, and would help control certain species of brush. As late as 1942, in fact, an estimated 210,000 angora goats, grazing mostly on the chaparral ranges in the central part of the State, produced over 1 million pounds of mohair (Rigden and Parker 1943).

Goats would help maximize returns from the chaparral because of the inherent differences in grazing habits between goats and cattle. McGinnies et al. (1941) state that ". . . cattle ordinarily will show a marked preference for grass but will make some use of weeds and shrubs. On the other hand, goats will make the greatest use of browse but to some extent will consume both grasses and weeds."

There are, however, subtle interactions between kind of grazing animal and productivity of the vegetation that depend on season of use, relative abundance of grasses and shrubs, species of shrubs present, intensity of use, and soil and climatic factors that should be considered before deciding on a specific kind or mix of animals.

On the Edwards Plateau in Texas, dual use by cattle and goats returned $4.75 gross per acre per year over a 20-year period, compared to $3.29 by cattle alone (Merrill et al. 1966, Merrill 1969). Goats would be particularly valuable for keeping sprouts grazed down on areas where fire or chemical shrub control treatments have been applied. This would permit a more productive grass cover to develop and provide a suitable forage mix for dual use by goats and cattle.

Number of Animals

Rates of stocking of chaparral ranges must be carefully adjusted to the available forage. This basic requirement is probably more important on chaparral ranges than on some others because of the strong competitive effects of shrubs. Too heavy grazing on interspersed grasses in poor vigor can cause rapid deterioration of the grass stand and invasion of broom snakeweed and other low-value plants. Too heavy browsing can also kill out the palatable shrubs (Rigden and Parker 1943). Humphrey (1964) recommends leaving at least one-fourth of the current year's twig growth at the end of the season. McCulloch (1955, as reported by Swank 1958) suggests that use should not exceed 30 to 35 percent of the current twig growth on most browse species.

Rich and Reynolds (1963) suggest that utilization of 40 percent of perennial grass production on chaparral lands characterized by an interspersion of shrubs and perennial grasses will enable the grasses to maintain a vigorous condition and provide adequate protection for the soil. They also state that chaparral lands in good condition have a grazing capacity of 5 to 15 acres per cow month (about 4 to 11 head per section yearlong). Humphrey (1960) suggests carrying capacity for chaparral range may vary from none to 15 head per section yearlong. Animal numbers are particularly important when cattle and sheep or cattle and goats are grazed on the same range, so that their numbers are balanced with the preferred forage for each (Rigden and Parker 1943).

Season of Grazing

Yearlong grazing is usual in the chaparral type because of the relatively mild climate and the presence of evergreen browse plants which provide forage and shelter during snowy periods (Rigden and Parker 1943). Chaparral is particularly well suited to yearlong use because of the differences in seasonal growth patterns between shrubs and grasses: the shrubs are more succulent and thus more palatable in spring (their main period of growth) than in summer, and the grasses are more palatable in summer (their main period of growth). Some chaparral ranges are especially valuable for fall-winter-spring grazing (Rich and Reynolds 1963).

Grazing Systems

Research on grazing systems for Arizona's chaparral ranges has been extremely limited. As a general recommendation for rangeland in Yavapai county, Humphrey (1964) suggests summer deferment every other year for deteriorated ranges, and once every 3 to 5 years for ranges in excellent condition.

In one field trial, the range was divided into four pastures for a rotation-deferred grazing system on an operating ranch in the chaparral type west of Prescott (Freeman 1961). All the cattle were kept in one pasture, and use of the pastures was rotated so that no pasture was grazed more than half of any one growing season or at the same season in any 2 successive years. After 2 years of operation the benefits of the plant were reported as (1) ease of looking after the cattle in a single herd, (2) increased vigor of perennial grasses, (3) perennial grasses establishing near watering places and in gullies, and (4) more even utilization resulting from salting away from water. After the first 2 years, the system was expanded to include the forest allotment as a five-pasture system. The system appears to be flexible enough to take care of variable grass production; use of major species was held to about 50 percent. The emphasis was on grass management, and no mention was made of shrub use.

Improving Forage Production

Seeding

Reseeding is a valuable tool in improving the condition and forage production of chaparral ranges, but all research indicates that the shrub stand must be severely reduced because of excessive competition between chaparral shrubs and grass seedlings.

In detailed recommendations for seeding in the chaparral type (Ariz. Agric. Exp. Stn. 1969), the type is subdivided into three environmental zones: (1) the Mohave chaparral, consisting of the lower, mountainous, northwest portion; (2) the Coronado chaparral, consisting of the isolated areas that surround mountain ranges in the southeastern part of Arizona; and (3) the Mogollon chaparral, containing the bulk of the type, that lies below the Mogollon Rim, between the other two zones. The Mohave and Mogollon portions are further subdivided into two precipitation ranges each, and recommendations are made for upland and bottomland sites in each of the type subdivisions.

The species recommended ". . . have been evaluated in many experimental and field plantings, . . . can be established with relative ease, . . . are persistent and maintain vigor under proper grazing management, . . . are available in commercial seed channels, . . . and have good forage value in the area where they are adapted." Sixteen species—two legumes (alfalfa, and yellow sweetclover) and 14 grasses—have a wide range of adaptability, but a few are very restricted. Lovegrasses and wheatgrasses dominate the grass recommendations (table 5). Interestingly, the most successful species tested by Lavin and Pase (1963), King Ranch bluestem, is not mentioned in the Experiment Station bulletin although a closely related species, Turkestan bluestem, is mentioned as showing promise but needing additional trials and field evaluation plantings.

The general recommendations for successful reseeding mentioned include:

- Use seed of adapted species only.
- Select areas with good potential for supporting good cover (do not seed shallow or rocky soils o excessively steep slopes).
- Prepare a suitable seedbed reasonably free fron competition of undesirable plants (control competin plants by mechanical, chemical, or burning treatments).
- Distribute seed evenly, cover at proper depth, an compact the soil around the seed. Drilling is th preferable method, especially with large-seede species, but broadcast seeding often gives satisfactor results, particularly with small-seeded species.
- Protect the seeded area until the stand is established.

Table 5.--Species recommended for seeding on upland (upper) and bottomland (lower) sites in various portions of the chaparral type

Species	MOHAVE ZONE Precipitation of-- 12-14 inches		MOHAVE ZONE Precipitation of-- 14-16 inches		MOGOLLON ZONE Precipitation of-- 14-18 inches		MOGOLLON ZONE Precipitation of-- 18-30 inches		CORONADO ZONE Precipitation of 17-20 inches	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Alfalfa				X		X	X	X		X
Yellow sweetclover		X	X	X	X	X	X	X	X	X
Sand dropseed	X	X								
Black grama	X		X		X				X	
Blue grama			X	X	X	X			X	X
Boer lovegrass	X	X	X	X	X	X			X	X
Lehmann lovegrass	X	X	X	X	X	X			X	X
Weeping lovegrass		X	X	X	X	X	X	X	X	X
Indian ricegrass	X	X	X	X	X	X				
Crested wheatgrass	X	X	X	X	X	X	X	X		
Intermediate wheatgrass				X		X	X	X		
Pubescent wheatgrass		X	X	X	X	X	X	X		
Siberian wheatgrass	X	X	X	X	X	X				
Western wheatgrass		X		X	X	X	X	X		
Spike muhly					X	X	X	X		
Tall fescue								X		
Orchardgrass							X	X		
Perennial ryegrass							X	X		

Reseeding trials following accidental chaparral fires in the Pinal and Mazatzal Mountains of central Arizona indicate that: (1) Weeping lovegrass establishes itself easily and can yield as much as 1,600 pounds per acre by the third year. However, it usually declines thereafter. The decline is due in part to increasing competition from the recovering shrubs, but since it also takes place on some shrub-free areas in the chaparral type, a nutrient deficiency may also be involved (Cable 1957, Pond and Cable 1962, Pond 1968). (2) Of 16 species of cool-season forbs and cool- and warm-season grasses, only Lehmann lovegrass and King Ranch bluestem rated good or excellent after the third growing season. Turkestan bluestem, weeping lovegrass, and black and Indian mustards rated fair. Buffelgrass was the most vigorous species the first year, but was not coldhardy enough to withstand the winters. Lehmann lovegrass maintained itself better than weeping lovegrass, but is not coldhardy enough for many chaparral sites (Lavin and Pase 1963).

One phase of reseeding research has been almost completely neglected in Arizona—seeding or planting palatable shrubs to improve forage conditions for livestock and wildlife. Such research should have a priority because of the important wildlife and recreation potential of chaparral areas. Considerable research of this kind has been conducted in Utah Plummer et al. 1968).

Plant Control

Control of undesirable shrubs not only is necessary to sucessful reseeding of grasses on chaparral ranges, but it also increases water yields and can benefit wildlife. The numerous methods of shrub control tried on chaparral ranges in Arizona can be grouped into several categories (Ariz. Agric. Exp. Stn. 1969, Hibbert et al. 1974):

- Mechanical—cabling, chaining, railing, flailing, mowing, root plowing, bulldozing.
- Burning.
- Chemical.
- Biological—plant pests, grazing animals.
- Combinations of one or more of the above.

Mechanical methods.—Most of the mechanical methods are not well adapted to chaparral. Methods such as cabling and chaining destroy only the aboveground parts of the plants; root crowns of most chaparral species then sprout prolifically. Bulldozing, which is effective in uprooting isolated clumps of shrubs, is a desirable method where a good understory of perennial grasses is present between the shrub clumps (Ariz. Agric. Exp. Stn. 1969).

Root plowing is the most effective mechanical method for controlling chaparral shrubs. This method involves pulling a heavy blade, attached horizontally to a crawler tractor (fig. 7), at a depth of from 8 to 18 inches in the soil (Pond and Bohning 1971). The Arizona Agricultural Experiment Station (1969), recommends a minimum depth of 12 inches for shrub live oak. The depth of the blade should be based on the type of root system of the dominant shrub present and on the soil type. The blade should be pulled just below the root crown (sprouting bud zone), so that it separates all roots from the root crown and lifts the severed plants out of the ground.

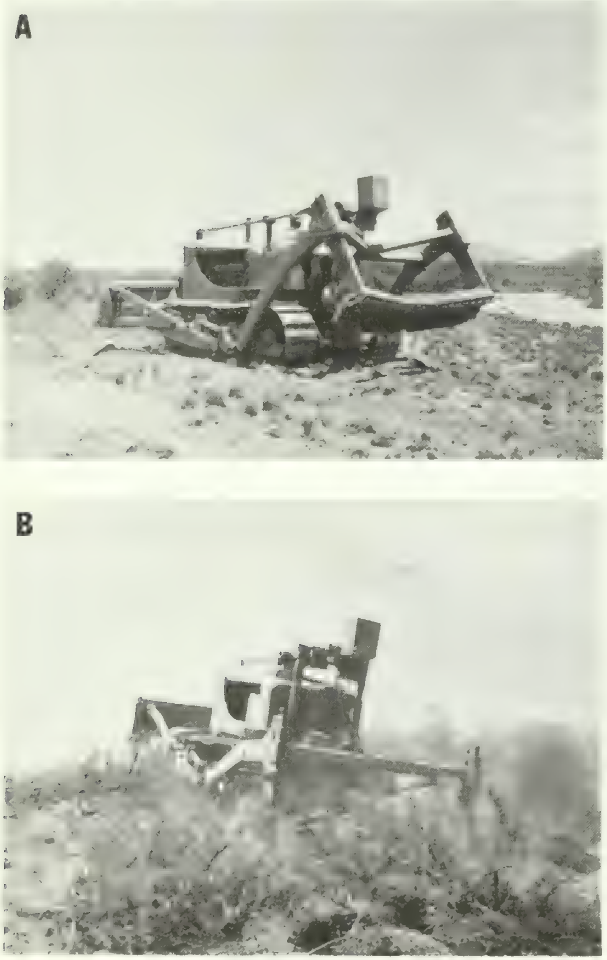


Figure 7.—
A, Tractor with 12-foot-wide root-plow blade.
B, In operation, grass seed is broadcast from rear of tractor.

Large rocks, gullies, and steep slopes severely restrict the area on which root plowing can be used. Pond (1961) estimates that 2 to 8 percent of the chaparral type can be safely root plowed. Where the root plow can be used, however, from 81 to 95 percent or more of the chaparral shrubs can be killed (Pond 1961, Pond et al. 1965), and grass production can be increased tremendously by seeding adapted species (fig. 8). Root plowing on relatively level chaparral should cost $20 to $25 per acre, and seeding behind the plow $5 or less per acre, depending on species and current seed costs.

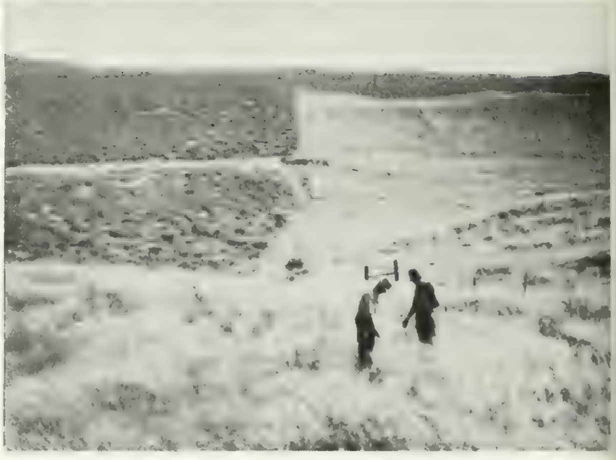
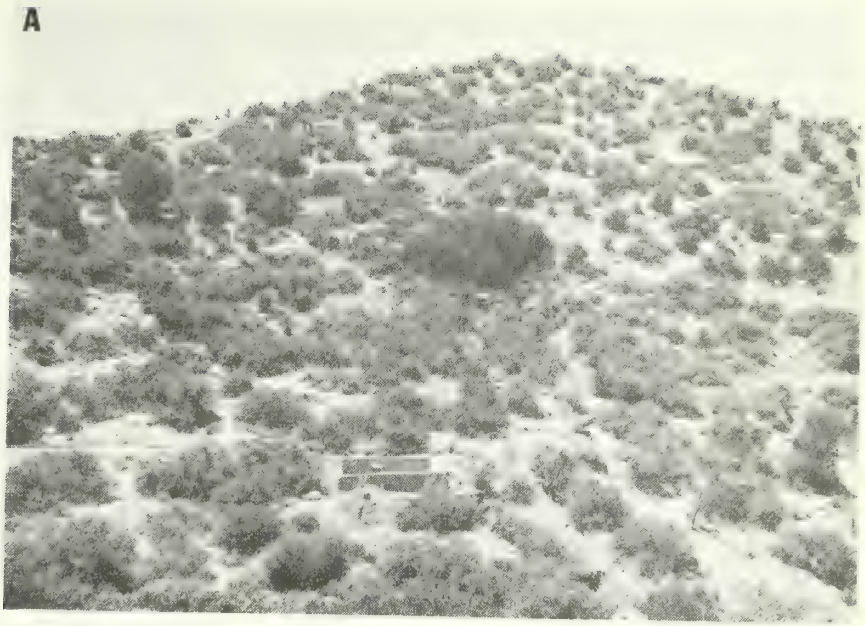


Figure 8.—Root-plowed area at Tonto Springs, Prescott National Forest, reseeded to weeping and Lehmann lovegrasses. (Photo by Ray Manley.)

Even on low-elevation ranges on granitic soils, removal of shrubs and seeding to Lehmann and Boer lovegrasses can greatly reduce erosion and increase forage production. At the Summit watersheds (elevation about 3,800 feet), grubbing shrubs and seeding grass increased grass basal area by 10 times and reduced erosion more than 99 percent in the following 7 years (Rich 1961) (fig. 9).

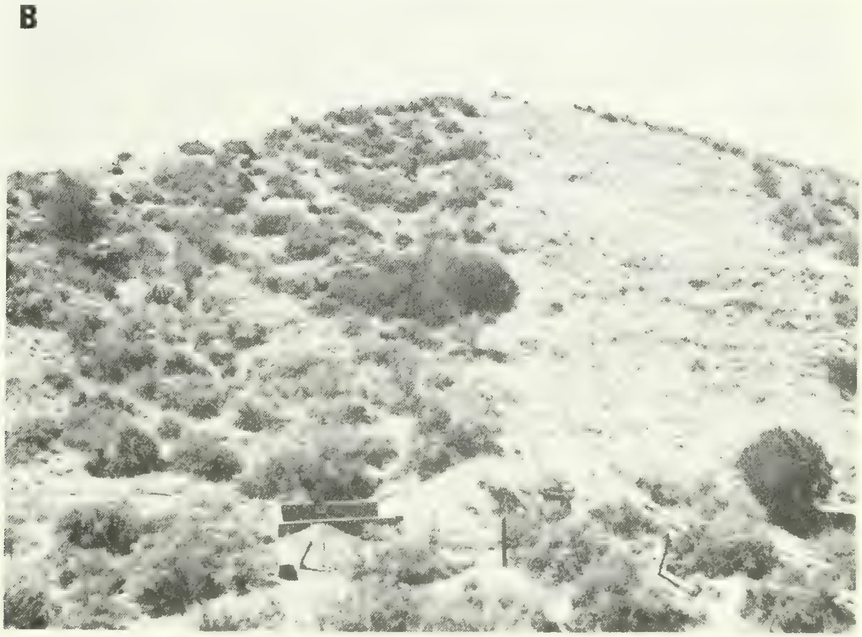
Burning.—Prescribed burning has been studied intermittently for many years as a possible method for controlling chaparral shrubs and creating openings in the stands. The natural fire resistance of several chaparral shrubs, particularly shrub live oak, was clearly demonstrated at Sierra Ancha, where five successive annual burnings were required to reduce the number of shrub live oak sprouts below preburn numbers (Pond and Cable 1960).

Burning must be combined with other types of control to improve forage production. Prescriptions for planned broadcast burning to kill the aboveground parts of chaparral shrubs, with minimum damage to herbaceous understory and the soil, have been developed by the Southwest Interagency Fire Council (1968). The SWIFCO guide indicates fall is the recommended season for burning chaparral in the Southwest. This is the period of high fire danger, but not so high that prescribed fires cannot be controlled. Within this season, conditions of humidity, wind, and fuel moisture can be prescribed that



igure 9.—Summit watersheds 6 (left) and 7 (right).

A, In 1936.



B, In 1960, 7 years after grubbing shrubs and seeding to Lehmann and Boer lovegrasses.

will produce a fast-moving fire with least damage to understory herbaceous vegetation and soil.

Specifications for successful chaparral burns (fig. 10) include:

- Vegetation must be dormant or nearly dormant.
- Wind should not exceed 4 miles per hour.
- Relative humidity should be between about 14 and 35 percent, with fuel stick moisture between about 8 and 18 percent.

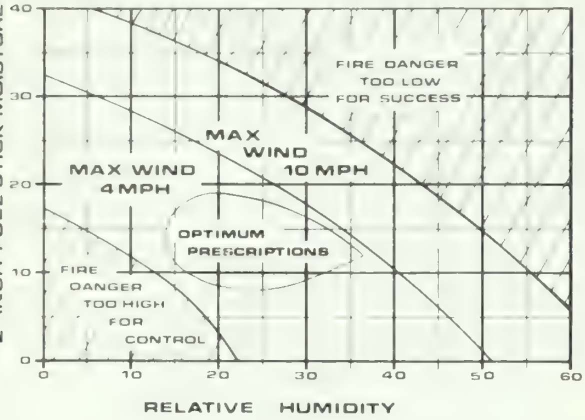


Figure 10.—Current recommendations for successful prescribed burning in Arizona chaparral (reprinted from Southwest Interagency Fire Council 1968).

Burning can be successful under more humid conditions if the vegetation has been treated with chemical desiccants to dry out the foliage (risk of escape would also be less under these conditions). In trials at Sierra Ancha, spraying a mixture of 2,4-D and 2,4,5-T 4 to 6 weeks prior to burning dried the shrub foliage to a little over 10 moisture (from about 90 percent), and the subsequent September burns topkilled most of the shrubs. These fires consumed from 22 to 51 percent of the litter, which left the soil better protected than a completely clean burn (Lindenmuth and Davis 1962, Lindenmuth and Glendening 1962, Pase and Glendening 1965, Pase and Lindenmuth 1971).

Burning a converted chaparral area in February (7 years after root plowing and seeding), when soil moisture was high and grass and leaf bases were relatively moist, resulted in a flashy fire that effectively topkilled shrub sprouts but did not harm the grass stand (primarily Lehmann lovegrass, and Turkestan and King Ranch bluestems) (Pase 1971). This type of burning, repeated periodically, might well offer a relatively cheap method of suppressing shrub growth on converted chaparral areas.

Chemical treatments.—Most research in the use of chemicals for chaparral control has concentrated on shrub live oak, because it is the major dominant over most of the type and one of the most difficult species to kill. Until recently, the phenoxy herbicides 2,4,5-T and silvex were the most effective chemicals available. Even with repeated annual applications, however, the more resistant species continued to sprout from the root crown (Lillie and Davis 1961, Lillie 1962, Lillie 1963, Pase 1967, Davis and Pase 1969).

Picloram (a picolinic acid) and fenuron (a substituted urea) appear to offer considerably more promise than the phenoxys. Lillie and Davis (1961) note that pelleted fenuron (25 percent active ingredient) not only killed mature oak when applied to field plants at 16 pounds per acre, but also that it killed all grasses and forbs. Pelleted fenuron applied by hand under channelside shrubs and trees at the Whitespar watersheds southwest of Prescott, at the rate of 23.2 pounds acid equivalent per acre (for shrub area actually treated), resulted in effective control. It was estimated (Ingebo 1971) that the single application of fenuron ". . . probably will eventually kill 80 percent or more of the chaparral cover, even the highly resistant shrub live oak." Because the intershrub spaces were not treated, the native grasses and forbs ". . . have exhibited renewed vigor since the elimination of competition."

More recently, karbutilate and bromacil have shown much promise for shrub control in experimental trials. Broadcast in the form of large pellets several feet apart, these materials adequately contro the shrubs with minimum damage to understory grasses (Hibbert et al. 1974).

Much research has been conducted on the effect of herbicides on fire sprouts. Such data probabl have general applicability to unburned chaparral although the larger more woody stems of unburne plants are more difficult to kill than are the tende stems of fire sprouts (Lillie and Davis 1961). I general, fire sprouts of the more resistant chaparra shrubs are difficult to kill even with repeate applications of 2,4,5-T.

Fenuron and picloram exhibited different degree of selectivity when applied as pellets to 6-year-ol sprouts of five shrub species (fenuron at 18 pound per acre of ground actually treated and picloram at pounds per acre). At the end of the third growin season, the percent shrub kills were as follows (Dav and Pase 1969):

	Shrubs killed with –	
	Fenuron	**Picloram**
	(Percent)	
Shrub live oak	82	56
Palmer oak	40	23
Birchleaf mountainmahogany	54	94
Sugar sumac	57	100
Yellowleaf silktassel	20	100

The differential susceptibilities, and the relatively high kills obtained, provide numerous possibilities for manipulating chaparral cover by using particular combinations of the two herbicides to favor or control specific species. Even more selectivity could be obtained by hand application or use of a low-flying helicopter. Spot application of pellets also minimizes damage to stands of understory grasses between the shrubs.

The available data suggest that many burned chaparral areas can produce 800 to 1,000 pounds of native and seeded perennial grasses per acre, if crown cover of sprouting shrubs can be held to less than 5 to 10 percent by chemical or other means.

Biological methods.—Biological methods of controlling undesirable vegetation include use of insect pests, competing vegetation, and browsing animals. No insect pests are known that are sufficiently destructive to control our chaparral shrubs. Also, since the less desirable shrub species are usually the more aggressive ones, they cannot be crowded out by the desirable species. Use of browsing animals, however, particularly goats, does offer some possibilities for shrub control. For example, Davis et al. (1975) describe how goats have been used successfully in Colorado to control Gambel oak sprouts. Management systems that include goats to graze the young shrub sprouts after an initial prescribed burn should be tested. A rotation-deferred grazing system designed around the relative forage contribution of grasses and shrubs and the seasonal grazing preferences of cattle and goats will be needed to provide optimum harvest of each class of forage. Periodic reburning may also be needed to topkill the shrubs and provide more succulent browse.

This kind of management system would be applicable to a large portion of the chaparral type. Grass seed can be broadcast aerially, and steep slopes offer no great barrier to grazing by goats.

Combination treatments.—Combination treatments generally produce better results, in terms of improving forage production, than single treatments.

(1) Fire-chemical. One of the big advantages of a combination of prescribed burning and use of chemicals is that these treatments can be applied on most of the chaparral type, regardless of topography. Reseeding also must be included in many of these combination treatments to obtain optimum herbaceous production, however. Initial results from one pilot-scale trial in central Arizona indicate an increase of 1,500 pounds of forage per acre and a reduction in fire hazard and fire suppression costs (Suhr 1967).

(2) Mechanical-chemical. The most successful combination treatment that did not involve burning consisted of control of sprouts after root plowing with spot applications of fenuron at 12 pounds per acre in December. Root-plowed and seeded pastures supported about three times as many cattle per acre as the chaparral pastures during the first 3 years after treatment. Yearlings on chaparral pastures produced 10.8 pounds of beef per acre per year, compared to 40.0 pounds per acre on root-plowed and seeded pastures (Pond 1967).

Numerous other combinations of control treatments are possible (fig. 11). Because the least expensive conversions involve fire as an initial treatment, burning has been proposed as the initial treatment in most chaparral-to-grass conversions (Courtney and Baldwin 1964, Proctor 1971). How-

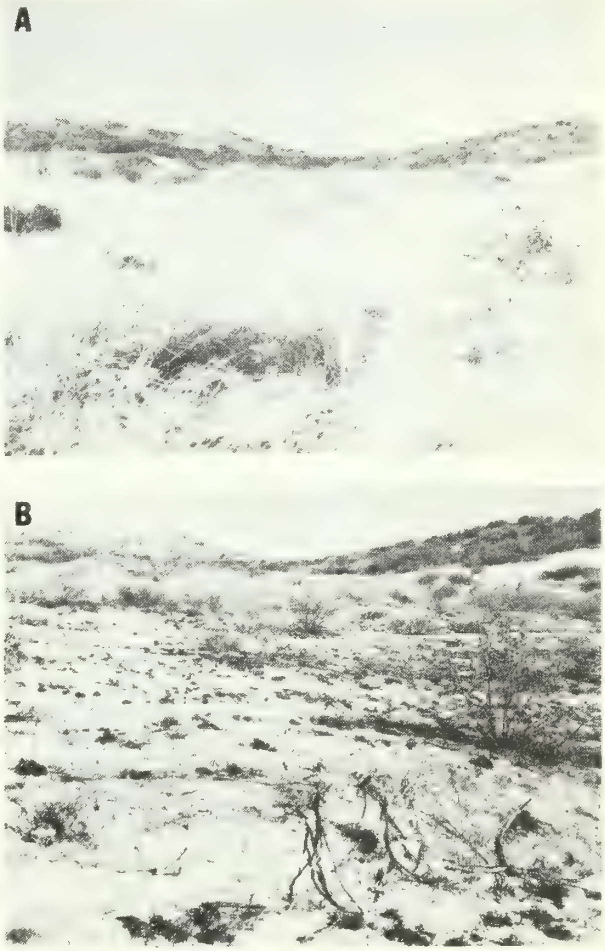


Figure 11.—Mechanical - chemical - burning treatments to convert chaparral to grass at Three-Bar:

A, Good stand of Lehmann lovegrass after root plowing and fenuron treatment (January 1969).

B, March 1969, after prescribed burn to control shrub sprouts. Unburned check plot in right background.

ever, any combination treatment to control chaparral shrubs and improve forage production must also consider grazing management. For example, an initial burn followed by reseeding of adapted grasses will generally result in a stand of grass and shrub sprouts. A proper rotation grazing system, then, would provide for goats to keep the shrub sprouts under control and cattle to harvest the grass. It might be necessary to reburn periodically to maintain minimum shrub competition.

Economic and Other Benefits of Conversion

Selection of specific areas of chaparral for conversion to grass must involve the economics of conversion as well as effects of other wildland values.

Few land managers will spend money on a range improvement practice without assurance that the benefits will at least pay for the cost of the treatment. Few cost-benefit analyses have been made for range improvement practices in the chaparral. However, a recent report by Brown et al. (1974) estimates costs and benefits to be expected from converting 139 specific areas in the Salt-Verde Basin best adapted to conversion from chaparral to grass. They indicate average annual per-acre benefits of 0.21 foot of additional runoff, 0.24 additional AUM of grazing, and a 34-cent reduction in fire fighting costs. These benefits add up to a net average annual return of $2.51 per converted acre, based on the best estimates of benefits on areas with more than 30 percent shrub cover and slopes less than 60 percent. Benefit-cost ratios varied from 0.1 to 6.4 on the 139 areas, and were 1.0 or greater on 96 areas. Other alternative conversion treatments gave lower benefits. While the cost and benefit values used in this analysis will change with time and may not apply exactly to any specific area, the methodology provides a means of evaluating the economic feasibility of chaparral-to-grass conversions.

The appearance of converted areas must also be considered. Openings must be designed so that they blend naturally with the landscape. Within these economic and esthetic constraints, benefits in the forms of increased grazing for domestic livestock and wildlife, and increased water yields and recreation opportunities can be expected from chaparral conversion. These benefits are discussed at appropriate places in the report.

Fertilizer Applications

Range fertilization is in the experimental stage in Arizona—it is not a common practice. Research to date indicates that addition of nitrogen provides the best response generally, with no essential difference between the different forms of nitrogen (Ariz. Agric. Exp. Stn. 1969). Addition of phosphorus or potassium has not significantly increased forage yields (Gary and Rich 1961). Other studies suggest that fertilizer may be beneficial on bottomland and upland sites in all three subdivisions of the Arizona chaparral type (Ariz. Agric. Exp. Stn. 1969). However, the necessity of adequate precipitation following fertilization, and the frequent lack of adequate summer precipitation, considerably restricts the chances for success. With adequate precipitation, grass production has increased up to 2.2 times (Anklam 1962, Bales 1965). Also, increased quality and palatability usually accompany increases in production. The present state of the art is such that no general recommendations are available for fertilizer application on chaparral range.

Increasing Usability of the Range

Water Development

Developments of permanent water in the chaparra type, largely by livestock interests, have consisted mostly of spring improvement (headboxes and troughs), and to a lesser extent, windmills and earth tanks. Swank (1958) states that "The development o free water has been rather extensive in Arizona chaparral" and estimates that not more than 15 percent of the chaparral range is more than 1 mile from water during the dry season.

For optimum distribution of cattle grazing in rough terrain, a rule-of-thumb guide is that cattle should not have to travel more than ¼ to ½ mile to water (USDA-SCS 1967). Under present condition of relatively low forage production in most of th chaparral type, the present distribution of waterin places may approach adequacy. However, afte treatment to improve forage production and wit more intensive management, additional water deve opments might be necessary. On the other hand limited experience with chaparral conversion t grass, (e.g. Brushy Basin on the Tonto National Forest, Suhr 1967) indicates that many previous intermittent streams become permanent followin conversion.

One promising technique in the field of rangelan water development is the horizontal well. Of 5 horizontal wells drilled on the San Carlos India Reservation in central Arizona (several on chaparra type land), 51 produced water; length varied from 3 to 273 feet (average 97 feet), and cost varied fro $190 to $735 (average $361.64) complete (Ari Cattle Growers' Assoc. 1969). (See also Welchert ar and Freeman 1973.)

Fencing

Dividing the range into suitably sized parcels,—based on availability of water, uniformity of topography and vegetation, class of livestock, and kind of grazing system used—is one of the most effective methods of obtaining proper distribution of grazing use (Stoddard and Smith 1955, USDA-SCS 1967). If sheep and goats are herded, fences are not needed. However, an increasing scarcity of competent herders has been a strong factor in the decline of sheep and goat numbers in Arizona. If cattle and sheep or goats are grazed together without herding, more pastures and better fences will probably be required than for cattle alone. Proper location of fences is especially important in the chaparral type (Freeman 1961, Suhr 1967).

Salt Placement

Proper placement of salt helps to obtain more uniform distribution of grazing use. Location of salt grounds in the chaparral type should follow the same principles as for other types (Stoddart and Smith 1955, USDA-SCS 1967):

- Pick openings in the brush on ridges or gentle slopes.
- Do not place salt at water or in low swales or other places where livestock naturally congregate.
- Salting in areas with species of low palatability will increase their utilization.
- In rough terrain, salt grounds should be not over ½ to 1 mile apart.
- Locations should be changed every year or two, or whenever the desirable forage plants show damage from trampling and grazing.

Salting away from water has been rather difficult to sell to many ranchers because of the belief that cattle like to drink after salting. However, this belief has been disproved in numerous instances, and salting away from water is becoming much more widespread. Freeman (1961) reports that a central Arizona rancher, when initiating a deferred-rotation grazing system in the chaparral type, also placed salt away from water (first about 1/8 mile, then ½ mile or farther). Salting away from water and changing salt grounds frequently encouraged cattle to graze away from water, and livestock distribution became more uniform.

Riding

Riding or herding is the most positive method of obtaining uniform distribution of livestock grazing, but it is also relatively expensive in labor cost and cannot be depended on to keep cattle in hilly areas if flatter areas are nearby.

Trail Construction

Use of graded trails in hilly and mountainous country often offers an opportunity to utilize areas that livestock would not be able to reach otherwise. This is particularly true with cattle; sheep and goats can be herded to most usable areas with little difficulty. Good trails can reduce use of steep slopes near watering facilities. Graded trails reduce the grazing use of nearby steep slopes by providing easy access to usable feed areas somewhat farther from water (Hendricks 1939, Stoddart and Smith 1955, USDA-SCS 1967).

Managing the Livestock

Nutrition

Proper nutrition of the grazing animals is vital to attaining optimum production on any range. Nutritive values and digestibility have been investigated in some detail for deer in the Arizona chaparral. Swank (1958) showed that protein content of shrubs averaged 15.1 percent during the spring growing period (April) in the Prescott area, and 12.8 percent in the Pinal Mountain area. On both areas, protein content averaged around 7 percent in July, January, and March. Mountainmahogany and desert ceanothus, both desirable species, showed the highest yearlong protein content, with hollyleaf buckthorn, also a desirable species, close behind. The two species of manzanita and Utah juniper, undesirable species, showed the lowest yearlong average protein content, with shrub live oak and most other shrub somewhat higher. Protein content of sprouts (some to 5 years old) on burned areas was higher than for those on adjacent nonburned areas.

Phosphorus content of shrubs was also highest during the spring growing period (0.32 and 0.25 percent on Prescott and Pinal Mountain areas, respectively) (Swank 1958). Phosphorus content gradually decreased to about 0.13 percent for the July, January, and March samples.

Analyses of first-year fire sprouts of shrub live oak, Wright silktassel, and birchleaf mountainmahogany for a 1-year period (1963-64) at Sierra Ancha (Reynolds 1967) showed a seasonal pattern of change in protein and phosphorus similar to that shown by Swank, but the levels were somewhat lower for both elements. Also, these data show a minor peak in late August corresponding to the summer regrowth period (there was no summer regrowth in 1954-55 on Swank's areas). The mountainmahogany showed the highest protein content and silktassel the lowest. Calcium trends were erratic seasonally and among species. As shown in other studies, crude protein and moisture content were linearly and directly related for all species.

McCulloch and Urness (1973) present detailed data on white-tailed and mule deer at all seasons of the year in the chaparral. They found that by selective grazing of plant parts and species, both deer maintained a relatively uniform level of protein throughout the year, adequate for growth and reproduction.

Nutritive studies with domestic livestock on chaparral are limited. In a study near Prescott, however, Pond (1967) reported that (1) monthly gains by yearling steers were greater on range seeded to weeping lovegrass than on chaparral from March through November, (2) cattle held their own on chaparral but not on grass in January and February, and (3) steers lost weight on both chaparral and grass in December.

Protection

Livestock on the range must be protected from a variety of hazards including predators and inclement weather. One benefit of chaparral, briefly alluded to previously, is that it provides protection for cattle as well as available forage during periods of extreme snowfall. In one such instance, following 50 inches of snow at Tonto Springs west of Prescott, 15 calves survived unattended for 12 days in a dense chaparral stand, even though they lost about 40 pounds each. On grass pastures in the vicinity, 4 head (of 195) died even though they had all been rescued the second day and fed hay for the rest of the period (Pond et al. 1968). Pond estimated that heavy snowfalls (although not as heavy as that of 1967) can be expected in about 1 year in 10.

Operational Costs and Returns

No detailed economic analyses of ranching operations in the chaparral type could be found in the literature. However, as with other ranching areas in the State, the unfavorable investment return under current land prices compared with other investment opportunities makes ranching for economic return unattractive. The appeal of ranching as a way of life, though, appears to be of sufficient value to enough people that livestock ranching will continue to be a major use on all range areas in the State for the foreseeable future (Smith and Martin 1970).

Overall averages for Yavapai County, where nearly half of the chaparral type in Arizona occurs, show carrying capacity of all rangeland to be about 10 head per section yearlong. Assuming production of one calf per cow year, worth about $150, and a land value of $3,000, the value of the calf represents a 5 percent gross return. Production expenses would use up about half of this return, leaving only 2½ percent return on the investment (Hayes 1971). For suitabl range on the Tonto and Prescott National Forests, using the same valuations, the average prope stocking rate of 9 head per section yearlong woul yield a net return on the investment of 2 percent.

Correlating Grazing with Other Uses

Water

The chaparral type, in its present condition, doe not contribute heavily to the water yield in Arizona Streamflow of a series of chaparral watershed averaged 1 inch, compared to from 2.4 to 6.5 inche for watersheds in the ponderosa pine type and 3. inches in mixed conifer (Brown 1970). Yields from watershed in the juniper type averaged 1 inch, th same as a chaparral watershed.

Despite the low water yield from untreate chaparral watersheds, yields following conversion t grass have approached those of the pine-fir an mixed conifer sites (Hibbert and Ingebo 1971). Th large increases presumably result from reduce transpiration when deep-rooted shrubs are replace by shallow-rooted grasses and forbs that use les water (Hibbert 1971). Yield increases from chapar ral-to-grass conversions have varied from none on dr sites with open stands of chaparral (Rich 1961) t more than 6 inches (an increase of five times pre treatment yield) on wet sites under dense shru stands (Hibbert and Ingebo 1971).

These differences in response to chaparral remov are related to total precipitation, to the character the shrub stand, and to the degree of weathering an fracturing of the substratum. Dense shrub stands o weathered or fractured substrata which enable wat (and shrub roots) to penetrate relatively deeply (20 40 feet) have high potential for increased water yiel with conversion to grass. Sparse shrub stands whe substrata are little weathered and fractured have lo potential for increased water yield.

Water yield in the chaparral type occurs largely the winter and spring; 85 percent of the yearly tot is produced from November to April. The increa following conversion to grass follows this san pattern, so that most of the increase would expected to reach a point of use (Hibbert and Ingel 1971). Runoff data indicate a strong relation betwe mean annual precipitation and the expected increa in water yields. Little increase can be expected annual precipitation is less than 17 inches, but f each additional inch of mean precipitation, wat yield increases about 0.74 inch (Hibbert et al. 197 (fig. 12).

The size of the increase in water yield followi shrub conversion also depends on the proportion the shrub cover removed. If shrubs are thinn

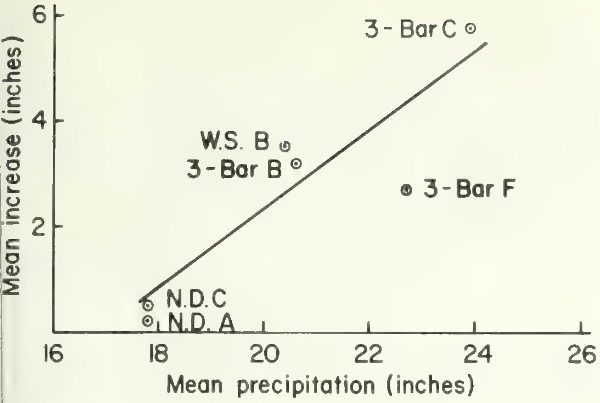
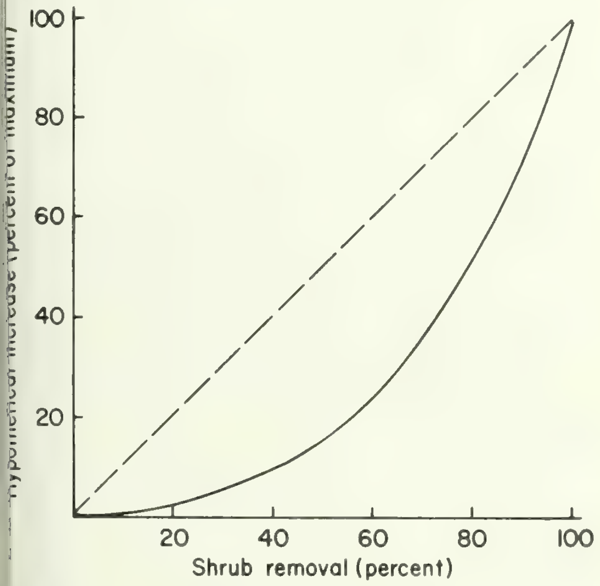


Figure 12.—Mean annual increase in water yield as a function of mean annual precipitation for experimental watersheds at Sierra Ancha, Whitespar, and Three-Bar (from Hibbert et al. 1974).

water yields will increase little—between 10 and 20 percent—for the first 50 percent of shrubs removed. Yields increase faster for later increments of shrub removal, as shown hypothetically in figure 13 (Hibbert et al. 1974).



igure 13.—Hypothetical increase in water yield as a function of percent of shrub cover removed in a thinning operation (from Hibbert et al. 1974).

The value of conversion to grass can be relatively igh. For example, an estimated 1.6 inch increase in water yield from 3,000 acres amounts to 400 acre-feet er year, or at $20 per acre-foot, a value of $8,000 er year. When benefits from increased livestock orage and reduced fire hazard are added, total benefits amount to $97 per acre over a 10-year period, against $30 per acre for cost of burning and chemical treatments (Suhr 1967, Brown and Boster 1974).

Sediment movement from dense natural chaparral is negligible, except for the rare unusually large, intense storm. Whenever the shrub cover is removed, as by fire, the protection of the shrub canopy is temporarily lost. Depending on the extent of damage to the litter cover, the unstable soils are exposed to the full impact of high-intensity summer storms. About 85 percent of the onsite soil movement on chaparral watersheds is carried by summer storms. Following a destructive wildfire that burned the Three-Bar watersheds in June 1959, sediment yields increased to 20,000 tons per square mile (about ¼ inch off the watershed). Sediment movement declined sharply as cover reestablished, and by the fourth postfire year, sediment yield was approaching the very low prefire levels (Pase and Ingebo 1965, Pase 1966). Sediment yields decreased fastest on a watershed where lovegrasses were seeded and shrub sprouts were suppressed by chemicals.

The runoff from summer storms is of short duration, and the sediment does not normally move very far. Winter runoff redistributes the sediments accumulated in the channels. Extreme precipitation events that come at intervals of several years flush out the builtup accumulations (Boster and Davis 1972).

Water-yield considerations have provided the major impetus for research on chaparral-to-grass conversions. However, the treatments that yield the largest increases in water yield also result in large increases in usable livestock forage. And along with the improvements in the water and grazing resource, wildlife and recreation values can be greatly improved with little or no loss to water and grazing values.

Wildlife

Wildife research in the chaparral type has been primarily concerned with deer. The desert mule deer ranges in the lower part of the chaparral type (to about 4,000 feet elevation) while white-tailed deer range from 3,000 feet upward (Urness et al. 1971).

Deer populations in Arizona chaparral vary from 4 to 5 per square mile in the drier areas, where shrub live oak and skunkbush sumac predominate, to 20 to 30 per square mile in the higher, wetter areas of mixed shrubs (Swank 1958). Deer populations are relatively low where the brush is dense and herbaceous understory is sparse. Urness (1974) found that deer spent ½ to ¼ as much time on chaparral areas cleared by plowing as in untreated brush. But he suggests the deer probably received much more benefit per unit of time on the cleared areas because of the relatively high volumes of high-quality forages (especially forbs), and because deer spent their time on these areas exclusively for feeding (they rested, ruminated, etc. on untreated areas).

The extent of competition between deer and cattle for herbaceous plants in the chaparral is not known, but probably is not serious, even though they generally prefer the same shrub species. In fact, the browse forage used by cattle probably far exceeds the herbaceous forage used by deer. All authorities agree that livestock and wildlife would both benefit from opening up the chaparral stand. Because of their need for escape cover, however, the optimum amount of clearing for deer would probably be much less than for cattle (Swank 1958, Pond and Bohning 1971, Urness et al. 1971).

Most chaparral treatments result in an increase in production of young, nutritious sprouts. This is especially true of treatments such as periodic burning, in which each treatment results in a renewal of sprout production and more browse forage for both livestock and deer.

Management plans for chaparral must provide not only enough browse for deer, but adequate escape cover as well. Although optimum patterns of brush and grass have not been investigated thoroughly, Urness (1974) suggests that some brush should be left on all slope aspects. Control areas can be of any length, but should not exceed about 300 to 400 yards in width, and probably no more than 50 percent of any area should be treated.

EMERGING DEMANDS FOR THE RESOURCE

In its present unimproved state, the chaparral type is used relatively little by the hunter and recreationist, primarily because the brush is thick, roads are few, and access is difficult. As openings are created in the chaparral, use by hunters and picnickers has increased. Thus it appears that good management for water, forage, and wildlife can be good recreational management as well.

SUMMARY AND EVALUATION

The 3 to 6 million acres of chaparral in Arizona constitute a valuable range resource that is being used far below its productive potential. Use and management of this resource are difficult because of the great diversity in environmental conditions (soils, slopes, elevations, precipitation, temperature, and other characteristics), and because of the great complexity of vegetation: a large number of shrubby species of varying productivity and palatability are present in many combinations in a wide range of densities, and with widely varying herbaceous understories.

Limited research and pilot trials involving conversions of chaparral to grass have shown that such conversions result in greatly increased grass and livestock production, greatly increased water yield, reduced fire hazard and fire suppression costs, and improved wildlife and recreation values.

Optimum management of the chaparral range requires:

- Improvement in the production of forage and opening of the stand by treatments designed to:
  1. Convert areas to grass, to provide interspersion and diversity of chaparral stands.
  2. Maintain portions of the shrub component in a young-sprout stage rather than a mature stage.
  3. Modify the shrub composition toward more palatable plants and fewer unpalatable plants.

- Improvement in range and livestock management by:
  1. Designing grazing systems to meet the physiological needs of the native and introduced forage species.
  2. Developing management techniques for dual use by cattle and goats on the same range.

Technical information needed to accomplish improvements and increased use in chaparral type includes:

- Development of a habitat type classification an associated management implications.
- Refined prescriptions for using fire as a tool fc controlling sprout growth or maintaining it in young, nutritious condition through timing an frequency of reburning, necessary amounts of fue and so forth.
- More selective chemicals to increase the usefulne of chemical shrub control, and particularly how thes treatments affect herbaceous and desirable brows cover.
- Additional seeding and planting methods f herbaceous and shrubby species that can be used c a wider variety of sites.
- Grazing systems to properly utilize the chaparr type in its present unimproved condition in co junction with areas converted to grass.

Necessary complementary research would provi information on: (1) how to measure shrub pr duction, (2) what levels of use the various species shrubs can tolerate, (3) how season of use affec grass and shrub production, (4) seasonal patterns physiological development of the major fora species, and effects of harvesting at various stages this development, and (5) changes in grazing use shrub sprouts with age of sprouts.

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COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

Common Name	Botanical Name
	Annual Grasses
Red brome	*Bromus rubens* L.
	Perennial Grasses
Black grama	*Bouteloua eriopoda* Torr.
Blue grama	*Bouteloua gracilis* (H.B.K.) Lag.
Bluestems	*Andropogon* spp.
Boer lovegrass	*Eragrostis chloromelas* Steud.
Buffelgrass	*Pennisetum ciliare* (L.) Link
Bullgrass	*Muhlenbergia emersleyi* Vasey
Crested wheatgrass	*Agropyron cristatum* (L.) Gaertn.
Curly mesquite	*Hilaria belangeri* (Steud.) Nash
Deergrass	*Muhlenbergia rigens* (Benth.) Hitchc.
Dropseed	*Sporobolus* spp.
Green sprangletop	*Leptochloa dubia* (H.B.K.) Nees
Hairy grama	*Bouteloua hirsuta* Lag.
Indian ricegrass	*Oryzopsis hymenoides* (Roem. & Schult.) Ricker
Intermediate wheatgrass	*Agropyron intermedium* (Host.) Beauv.
King Ranch bluestem	*Andropogon ischaemum* var. King Ranch
Lehmann lovegrass	*Eragrostis lehmanniana* Nees
Little bluestem	*Andropogon scoparius* Michx.
Longtongue mutton bluegrass	*Poa longiligula* Scribn. & Williams
Lovegrass	*Eragrostis* spp.
Orchardgrass	*Dactylis glomerata* L.
Perennial ryegrass	*Lolium perenne* L.
Plains lovegrass	*Eragrostis intermedia* Hitchc.
Pubescent wheatgrass	*Agropyron trichophorum* (Link) Richt.
Sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray
Side-oats grama	*Bouteloua curtipendula* (Michx.) Torr.
Siberian wheatgrass	*Agropyron sibericum* (Willd.)
Spike muhly	*Muhlenbergia wrightii* Vasey
Squirreltail	*Sitanion* spp.
Tall fescue	*Festuca arundinaceae* Schreb.
Tall threeawns	*Aristida hamulosa* Henr. and *A. ternipes* Cav.
Threeawn	*Aristida* spp.
Turkestan bluestem	*Andropogon ischaemum* L.
Weeping lovegrass	*Eragrostis curvula* (Schrad.) Nees
Western wheatgrass	*Agropyron smithii* Rydb.
Wheatgrass	*Agropyron* spp.
Wolftail (Texas timothy)	*Lycurus phleoides* H.B.K.
	Forbs and Half Shrubs
Alfalfa	*Medicago sativa* L.
Black mustard	*Brassica nigra* (L.) Koch
Broom snakeweed	*Gutierrezia sarothrae* (Pursh.) Britt. & Rusby
Indian mustard	*Brassica juncea* (L.) Cosson
Purslane	*Portulaca* spp.
Spurge	*Euphorbia* spp.
Toadflax penstemon	*Penstemon linarioides* A. Gray
Wright eriogonum	*Eriogonum wrightii* Torr.
Yellow sweetclover	*Melilotus officinalis* (L.) Lam.

Common Name	Botanical Name
Trees and Shrubs	
Arizona white oak	*Quercus arizonica* Sarg.
Birchleaf mountainmahogany	*Cercocarpus betuloides* Nutt.
California jojoba	*Simmondsia chinensis* (Link) Schneid.
Catclaw acacia	*Acacia greggii* A. Gray
Catclaw mimosa	*Mimosa biuncifera* Benth.
Cliffrose	*Cowania mexicana* D. Don
Datil yucca	*Yucca baccata* Torr.
Deerbrush	*Ceanothus integerrimus* Hook. & Arn.
Desert ceanothus	*Ceanothus greggii* A. Gray
Emory oak	*Quercus emoryi* Torr.
Fir	*Abies* spp.
Hairy mountainmahogany	*Cercocarpus breviflorus* A. Gray
Hollyleaf buckthorn	*Rhamnus crocea* Nutt.
Jumping cholla	*Opuntia fulgida* Engelm.
Juniper	*Juniperus* spp.
Manzanita	*Arctostaphylos* spp.
Mescat acacia	*Acacia constricta* Benth.
Mountainmahogany	*Cercocarpus* spp.
Narrowleaf yerba-santa	*Eriodictyon angustifolium* Nutt.
Nolina	*Nolina* spp.
One-seed juniper	*Juniperus monosperma* (Engelm.) Sarg.
Palmer oak	*Quercus palmeri* (Engelm.) Sarg.
Palo verde	*Cercidium* spp.
Pine	*Pinus* spp.
Pinyon pine	*Pinus edulis* Engelm.
Pointleaf manzanita	*Arctostaphylos pungens* H.B.K.
Ponderosa pine	*Pinus ponderosa* Lawson
Pringle manzanita	*Arctostaphylos pringlei* Parry
Shrub live oak	*Quercus turbinella* Greene
Skunkbush sumac	*Rhus trilobata* Nutt.
Sugar sumac	*Rhus ovata* S. Wats.
True mountainmahogany	*Cercocarpus montanus* Raf.
Utah juniper	*Juniperus osteosperma* (Torr.) Little
Velvet mesquite	*Prosopis juliflora* var. *velutina* (Woot.) Sarg.
Wright silktassel	*Garrya wrightii* Torr.
Yellowleaf silktassel	*Garrya flavescens* S. Wats.

Agriculture—CSU, Ft. Col

Cable, Dwight R.
1975. Range management in the chaparral type and its ecological basis: The status of our knowledge. USDA For. Serv. Res. Pap. RM-155,30 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Chaparral in Arizona is used far below its potential. Conversions to grass can greatly increase water and grass production, and improve wildlife habitat. Management options include conversion to grass, maintaining shrubs in a sprout stage, changing shrub composition, reseeding, and using goats to harvest shrub forage.

Keywords: Chaparral, range management.

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Although this report discusses research involving pesticides, such research does not imply that the pesticide has been registered or recommended for the use studied. Registration is necessary before any pesticide can be recommended. If not handled or applied properly, pesticides can be injurious to humans, domestic animals, desirable plants, fish, and wildlife. Always **read** and **follow** the directions on the pesticide container.

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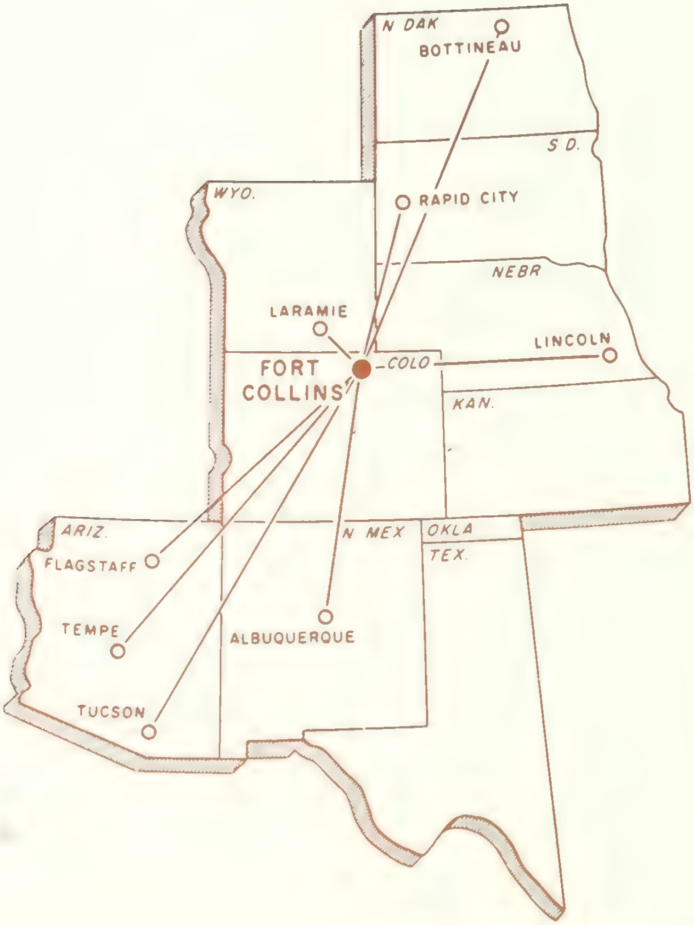
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ECOLOGY AND MANAGEMENT OF SOUTHWESTERN SEMIDESERT GRASS-SHRUB RANGES:

The Status of Our Knowledge

S. Clark Martin

November 1975
USDA Forest Service
Research Paper RM-156

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Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Martin, S. Clark.
1975. Ecology and management of southwestern semidesert grass-shrub ranges: The status of our knowledge. USDA For. Serv. Res. Pap. RM-156, 39 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

The vegetation on much southwestern semidesert range has shifted from grassland to brush since livestock ranching began back 100 years ago. Shrub control, reseeding, and improved grazing management have reversed the downward trend on some ranges but most ranges are producing below their potential. Grazing will continue to be a major use for semidesert range despite high land prices and increased recreational activity from an expanding urban population. The role of ranges in meat production will become more important as increased population requires that arable lands be used mainly for food production. Additional research needs include the evaluation of: improved grazing systems, prescribed burning, and impacts of range improvement practices on wildlife, scenic beauty and other recreational attributes.

Keywords: Semidesert range, grazing system, plant control, multiple use.

USDA Forest Service
Research Paper RM-156

November 1975

FOREST SERVICE
ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
240 West Prospect Street
Fort Collins, Colorado 80521

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ERRATA

Page 7 - Paragraph 5, line 5 should read:
...the impact of unwise grazing was "Stock eat the...

Page 15 - Paragraph 4, No. 7 of "Grazing schedules that have not been noticeably superior to yearlong grazing..." should read:
7. Rest July through October--graze November through February--then rest March through June; 1 year in 2.

Page 30 - Paragraph 2 of Summary, line 2 should read:
...priority for continued research in increasing range usability is relatively low.

OF

CONTENTS

Page

INTRODUCTION . . . 1
PHYSICAL CHARACTERISTICS . . . 1
  Climate . . . 1
  Geology and Soils . . . 2
BIOLOGICAL CHARACTERISTICS . . . 3
  Plant Communities . . . 3
  Precipitation and Plant Growth . . . 5
  Grazing and Vegetation Change . . . 6
SOCIAL AND ECONOMIC FACTORS . . . 7
  Historical Development . . . 7
  Current Situation . . . 7
  Ranch Operations . . . 9
  Energy Relations . . . 9
RANGE MANAGEMENT PRACTICES . . . 9
  Obtaining Proper Grazing Use . . . 10
    Kind of Animal . . . 10
    Number of Animals . . . 10
    Season of Grazing . . . 14
    Grazing Systems . . . 14
  Factors Affecting Forage Production . . . 17
    Rainfall . . . 17
    Range Condition, Grazing, and Drought . . . 18
    Site Potential . . . 18
  Seeding . . . 19
  Plant Control . . . 20
    Mesquite . . . 20
    Creosotebush . . . 23
    Cactus . . . 23
    Burroweed . . . 25
    Snakeweed . . . 25
    Summary . . . 25
  Rodent and Rabbit Control . . . 26
  Fertilizer Applications . . . 26
  Water Spreading . . . 27
  Increasing Usability of the Range . . . 27
    Water Development . . . 27
    Fencing . . . 29
    Salting . . . 29
    Riding . . . 29
    Trail Construction . . . 29
    Summary . . . 30
  Livestock Management . . . 30
    Animal Nutrition . . . 30
    Animal Breeding . . . 30
    Herd Composition . . . 31
    Flexible or Constant Stocking . . . 32
    Summary . . . 32
  Correlating Grazing With Other Uses . . . 32
    Water and Wood . . . 32
    Wildlife . . . 33
    Recreation . . . 33
RESEARCH RECOMMENDATIONS . . . 33
SUMMARY AND CONCLUSIONS . . . 34
LITERATURE CITED . . . 35
COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED . . . 39

ECOLOGY AND MANAGEMENT OF SOUTHWESTERN SEMIDESERT GRASS-SHRUB RANGES:

The Status of Our Knowledge

INTRODUCTION

Southwestern grass-shrub ranges have supported a viable livestock industry for well over a hundred years. Livestock production has progressed from the boom and bust days of the open range, when drought periodically reduced the numbers of both animals and ranchers, to the relatively stable situation now provided by ranch boundaries and clearly defined property rights. Meanwhile the art and science of ange management has also progressed. The primary oncern no longer is simply to harvest the forage. Rather, emphasis is now placed on developing and maintaining the most productive stand of forage and grazing it in a manner that insures continued high production without detriment to other land uses. This publication summarizes the results of research nd experience from many sources. Literature citations are provided for those who need more detailed information. The purpose in preparing this report has been to provide ranchers and range administrators with a brief statement of what is now known bout the ecology and management of semidesert grass-shrub ranges, and to point out a few of the obvious gaps in existing knowledge.

Southwestern semidesert grass-shrub vegetation occupies a strip 50 to 100 miles wide along the southern boundaries of Arizona, New Mexico, and west Texas. Generally, it is a sparsely populated region of open spaces where most of the land is devoted to range livestock production.

PHYSICAL CHARACTERISTICS

Climate

The climate of the semidesert region is characterized by mild and open winters, and warm to hot summers. Relative humidities are low throughout the year except during storm periods. Average annual precipitation ranges from about 8 inches at its western edge west of Tucson to around 20 inches in areas adjacent to mountain ranges in southeastern Arizona and at the eastern edge of the region in west Texas (fig. 1). At least half of the area receives less than 10 inches precipitation per year.

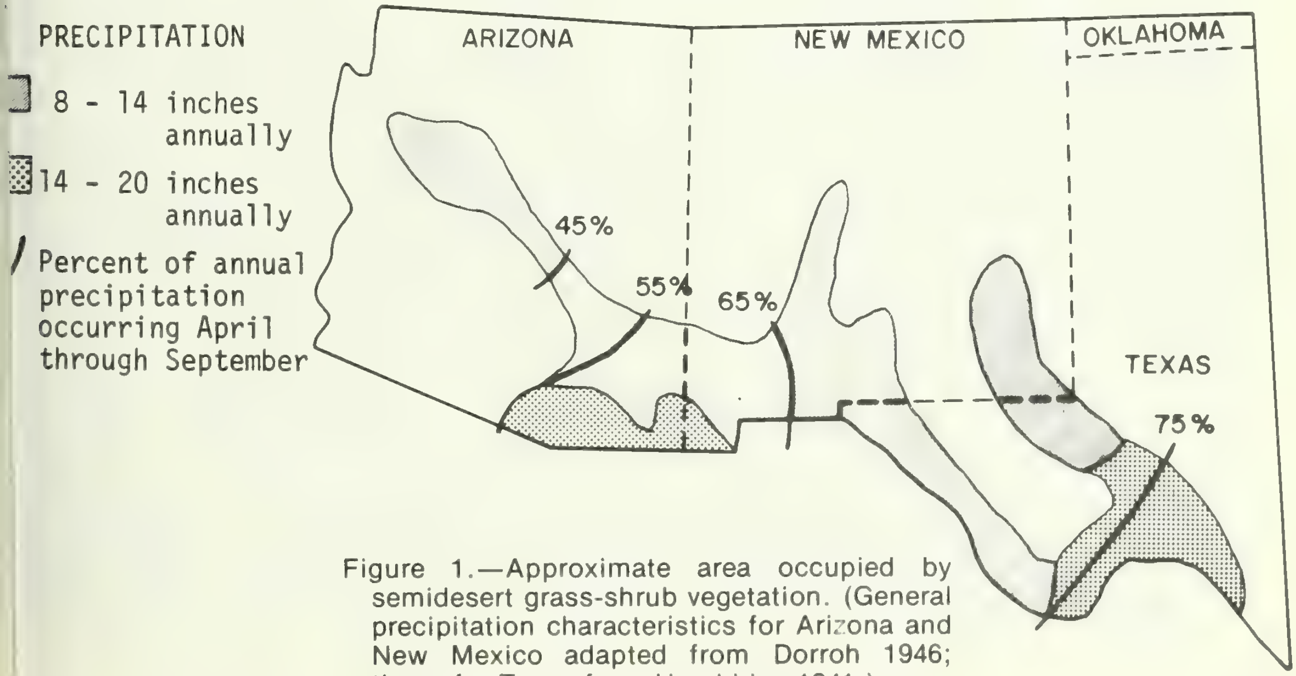

Figure 1.—Approximate area occupied by semidesert grass-shrub vegetation. (General precipitation characteristics for Arizona and New Mexico adapted from Dorroh 1946; those for Texas from Hambidge 1941.)

Sources of moisture for precipitation are the Pacific Ocean and the Gulf of Mexico. Moisture from the Pacific normally comes to the area during the winter months, and that from the Gulf during the summer, so there are two distinct rainy periods. Proximity to the source of moisture has an evident bearing on the seasonal distribution of rainfall. At Yuma, the point nearest the Pacific, less than 45 percent of the yearly rainfall comes during the April-to-September period, whereas almost 75 percent of the yearly rainfall comes during this period in the Big Bend area of Texas, near the Gulf of Mexico.

A major difference in precipitation distribution from the standpoint of grass production is the amount of rain in April, May, and June. At Tucson, Arizona, for example, no effective rain is expected in May and June. Here the summer monsoon begins around mid-July, although scattered thundershowers normally precede the onset of effective summer rains. In eastern New Mexico and west Texas, however, precipitation may begin in late April, and effective rainfall is expected in May and June. Hambidge (1941) shows that only 8 percent of the annual rainfall at Tucson comes in April, May, and June compared to 31 percent at Sonora, Texas. These differences in seasonal distribution of precipitatio bear significantly on plant growth and must b recognized in designing grazing systems.

Geology and Soils

Most semidesert range ecosystems in the Southwest are relatively flat, and from 3,000 to 5,000 fe in elevation. The otherwise gentle terrain is inte rupted by mountain ranges that rise abruptly elevations of 9,000 feet or more.

Soils are typically those of the semidesert. Th Mesa and Upland soils of the black grama commu ity are light, shallow, and usually 12 inches or less depth and frequently underlain by caliche. Th mixed grama and mesquite grassland types occur a wide variety of soils. Creosotebush usually associated with calcareous soils, and is often unde lain by caliche. It is also found in valley fills a other deep soils of alluvial origin.

The more common semidesert grasses and shru thrive on a variety of conditions of topography a soil. Still, the importance of these factors in vege

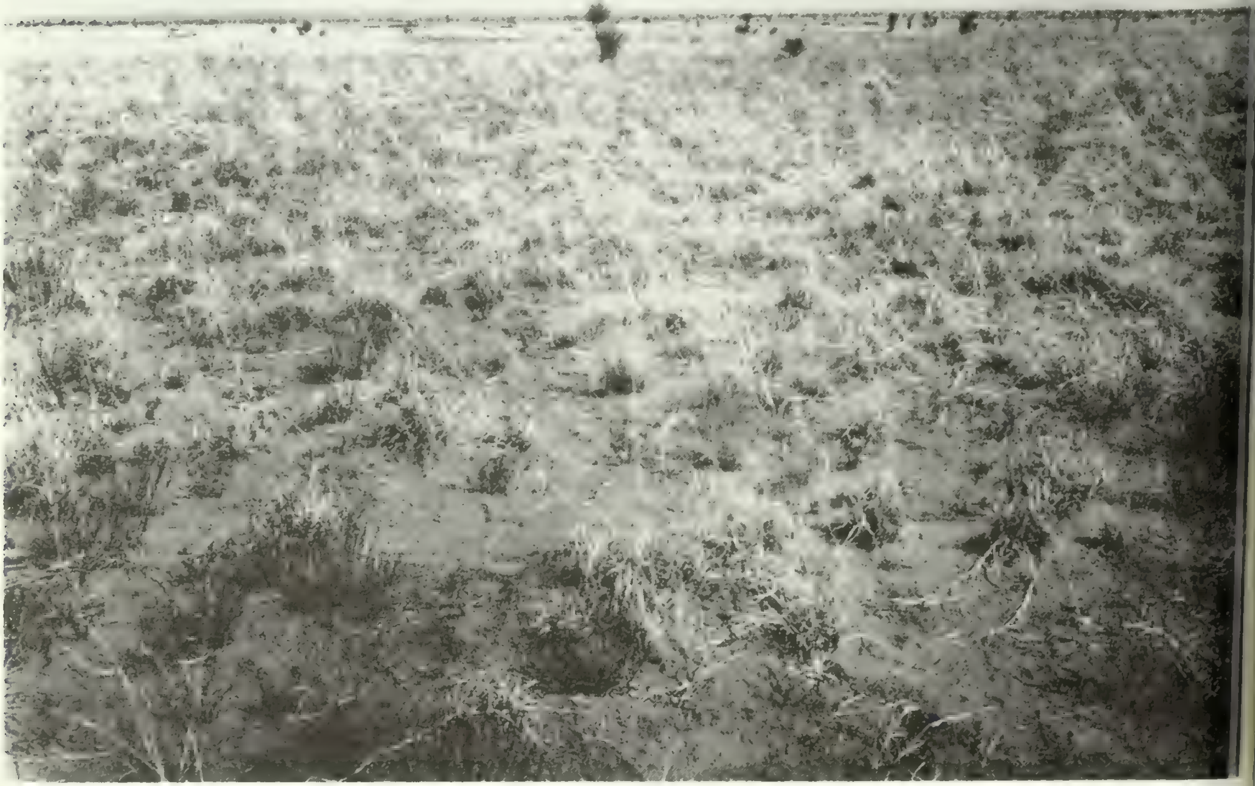

Figure 2.—Black grama range in southern New Mexico. Associated plants are mesa dropseed, snakeweed, and soaptree yucca.

ion development is evidenced by numerous examples n which a sharp vegetation change delineates a hange in soil or slope. Generally speaking, the basic auses have not been worked out for even the most triking soil-related vegetation differences, much less or the myriads of more subtle differences that ndoubtedly exist.

BIOLOGICAL CHARACTERISTICS

Plant Communities

Grass-shrub communities occupy extensive acre- ges in the Southwest between 3,000 and 5,000 feet levation. The perennial vegetation below about ,000 feet consists mainly of desert shrubs, domi- ated in many places by creosotebush.[2] Above about ,000 feet the grass-shrub type gives way to chapar- al, pinyon-juniper or oak woodland, or occasionally to grassland. The forage supply consists mainly of perennial grasses, but browse species and annual grasses are sometimes important.

The vegetation of the semidesert has been classified in various ways. Kuchler (1964) includes the following vegetation types in the area: Mesquite bosques, creosotebush, creosotebush-tarbush, grama-tobosa, shrubsteppe, and transpecos shrub savanna. Lowe (1964) includes most of the area in the southwestern desertscrub and desert grassland formations. The semidesert includes such ecological groupings as "mesquite grass" (Shantz and Zon 1936), "desert plains" (Weaver and Clements 1938), "desert grass" (Nichol 1952), "mesquite-grasslands" or "mesquite-half-shrub" (Darrow 1944), and "desert grassland" (Humphrey 1958).

The major vegetational communities include the black grama grassland of New Mexico and west Texas (fig. 2), the flood plains or flats of tobosa, sacaton, or alkali sacaton that occur along watercourses (fig. 3), the mixed grama grasslands (fig. 4), the mesquite-infested grasslands (fig. 5), the widespread creosotebush stands (fig. 6), and the tarbush, whitethorn, creosotebush areas of adjoining and included portions of the Chihuahuan desert (fig. 7).

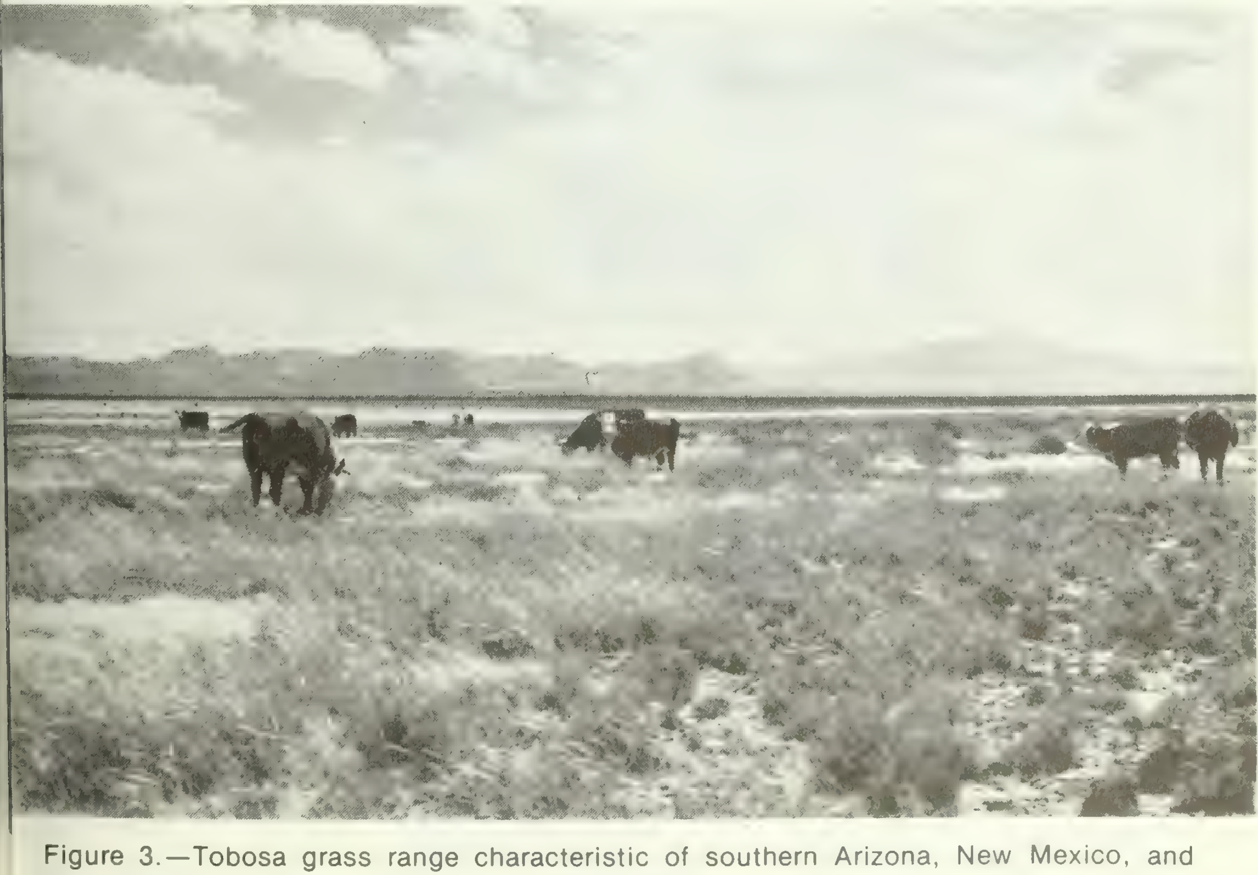

Figure 3.—Tobosa grass range characteristic of southern Arizona, New Mexico, and west Texas.

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[2] *Common and botanical names of plants mentioned re listed at the end of this paper. Nomenclature follows earney and Peebles (1951).*

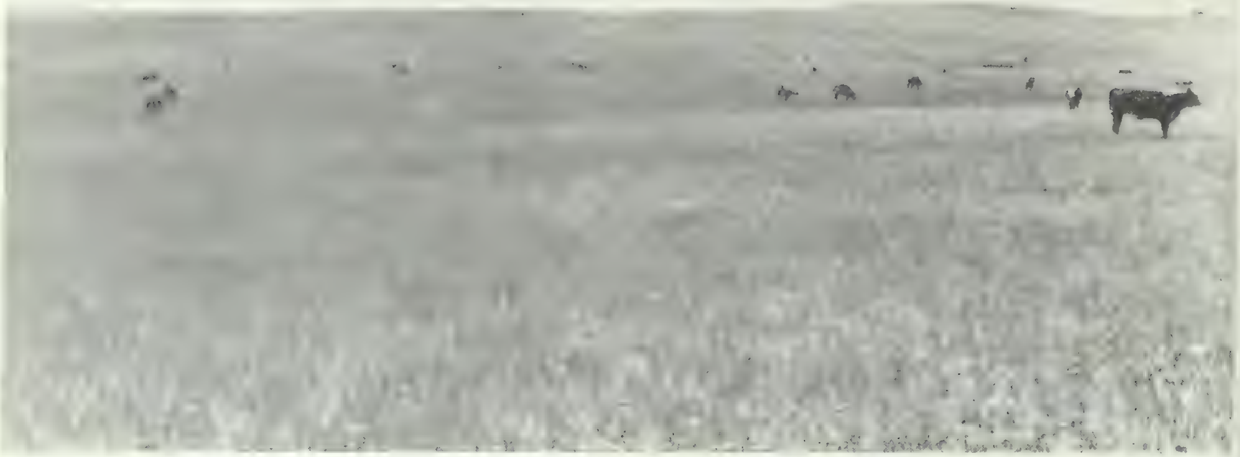

Figure 4.—Mixed grama range in southern Arizona. Dominant species are the short gramas (blue, hairy, and sprucetop) together with curly mesquite and threeawns.

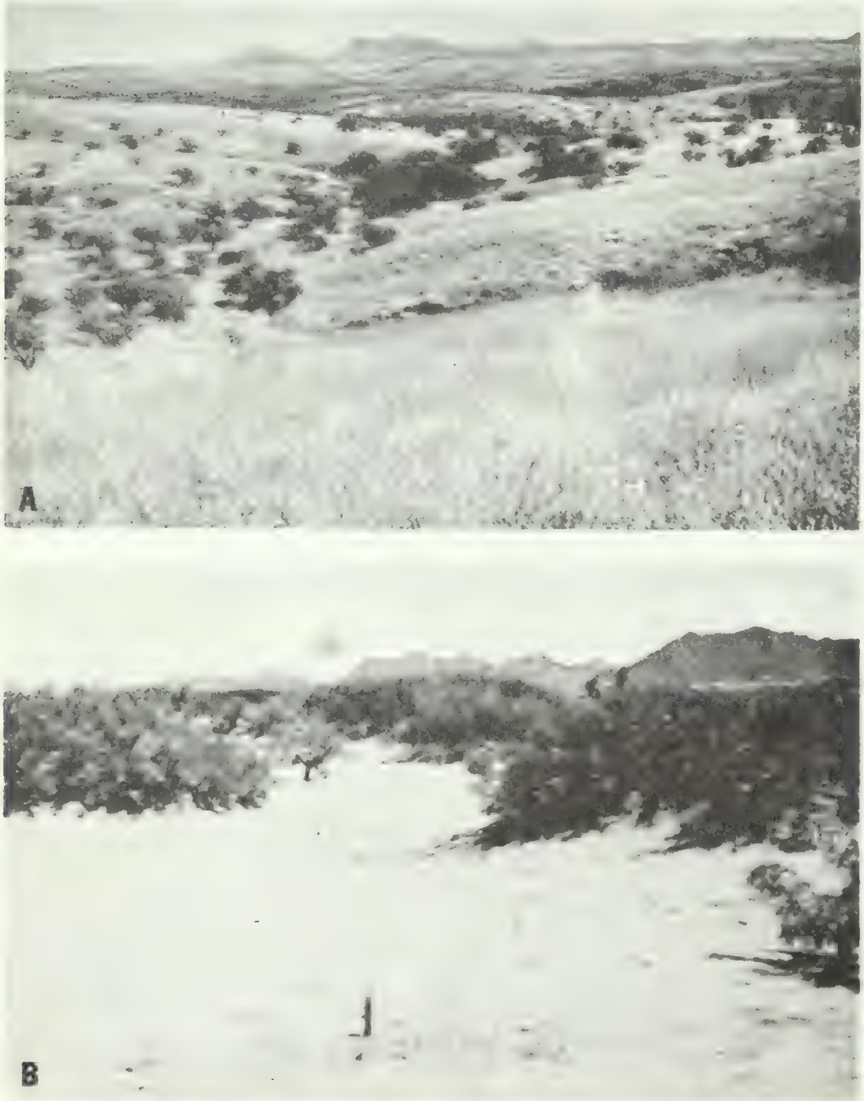

Figure 5.—Mesquite-infeste grasslands:

A, light stand of invadin mesquite on southern Ari zona grassland;

B, former black gram range in New Mexico no occupied by dune-typ mesquite.

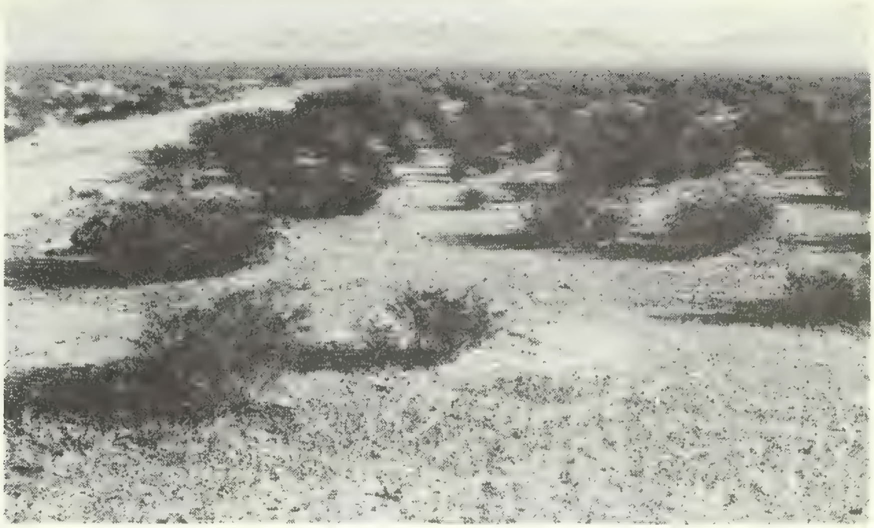

Figure 6.—Typical creosotebush stand in southern Arizona. Such stands support almost no herbaceous vegetation.

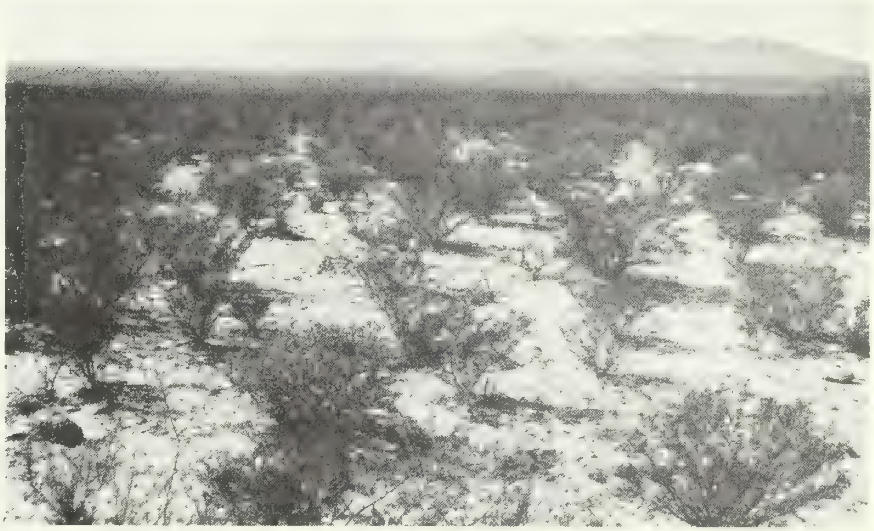

Figure 7.—Mixture of tarbush, whitethorn, and creosotebush, a typical chihuahuan desert mixture, in southeastern Arizona. (Univ. Ariz. photo.)

Precipitation and Plant Growth

Perennial grasses are the most reliable source of orage on semidesert ranges. These grasses grow henever moisture is available and temperatures are avorable. In southern Arizona the summer rainy eriod, July, August, and the early part of Septemer, produces about 90 percent of the year's herbage Culley 1943). Growth in March and April from inter and early spring precipitation produces only a mall amount of herbage. Grasses usually are ormant in May and June due to seasonal drought. arther east, in New Mexico and Texas, rains in pril, May, and June usually produce substantial rage.

In south-central New Mexico, Nelson (1934) bserved that black grama increased or decreased om one fall to the next depending on the vigor of e plant at the start of the current season, and that urrent-season vigor was related to rainfall during the previous year or summer. Also, Lister and Schumacher (1937) found that the most beneficial precipitation distribution for black and Rothrock gramas was a relatively dry winter between wet autumns and springs. Paulsen and Ares (1962) reported that the basal area of perennial grasses in the fall correlated best with precipitation for the 15-month period ending September 30 of the year of measurement.

More recent studies in southern Arizona have shown that herbage production in a given summer is related not only to current summer rainfall, but to rainfall during previous growing periods (Cable 1975). The reason is that the culms that produce herbage during the current summer originated as basal buds that broke dormancy either during the preceding spring, or more commonly, the preceding fall. Consequently, if a dry summer and a dry spring precede a summer of high rainfall, herbage production will be relatively low because the number of herbage-producing culms is low. On the other hand, two good rainfall summers in succession, or a good rainfall summer preceded by an exceptional spring, can be expected to produce high forage yields. Ground cover of perennial grasses likewise increases mainly after two consecutive good growth periods. A wet fall, or a wet winter and spring, activates basal buds and enlarges individual plants. The practical implication of this phenomenon is that it takes 2 years to produce a grass crop. Grazing systems based on the assumption that each year's forage production is an independent event simply do not fit the situation.

Grazing and Vegetation Change

The entire semidesert region has changed in the last 100 years. Griffiths (1901) cited testimony of ranchers as to the decline in range forage production and increases in gully erosion. Grazing by domestic animals has generally reduced the abundance and production of preferred forage grasses. In many places these preferred forage plants have been replaced in some degree by less desirable plants. The vegetation of ranges that have been most severely grazed is usually dominated by plants that are not palatable to livestock. Shrubs, unpalatable forbs, and annual grasses or short-lived perennial grasses are characteristic of ranges that have suffered past abuse. Conversely, ranges that support a vigorous stand of native perennial grasses, particularly those with a high percentage of midgrasses, are considered to be in reasonably good condition.

The condition of many ranges has been depressed so long that no standard of potential is available. Other ranges have improved greatly during the last three or four decades. Still, semidesert ranges that are in uniformly good to excellent condition are exceptional. Generally speaking, ranges with the lowest potential are in the worst condition. Many ranges that are in generally good condition also include spots where productivity is far below potential.

The most widespread, general manifestation o range deterioration is an increase in shrubby vegetation. Mesquite, creosotebush, pricklypear and choll cacti, burroweed, snakeweed, and various acacia have replaced grasses on much of the area (fig. 8). Invasions by these species usually have been accompanied by decreased herbage production as well as b substantial increases in sheet and gully erosion.

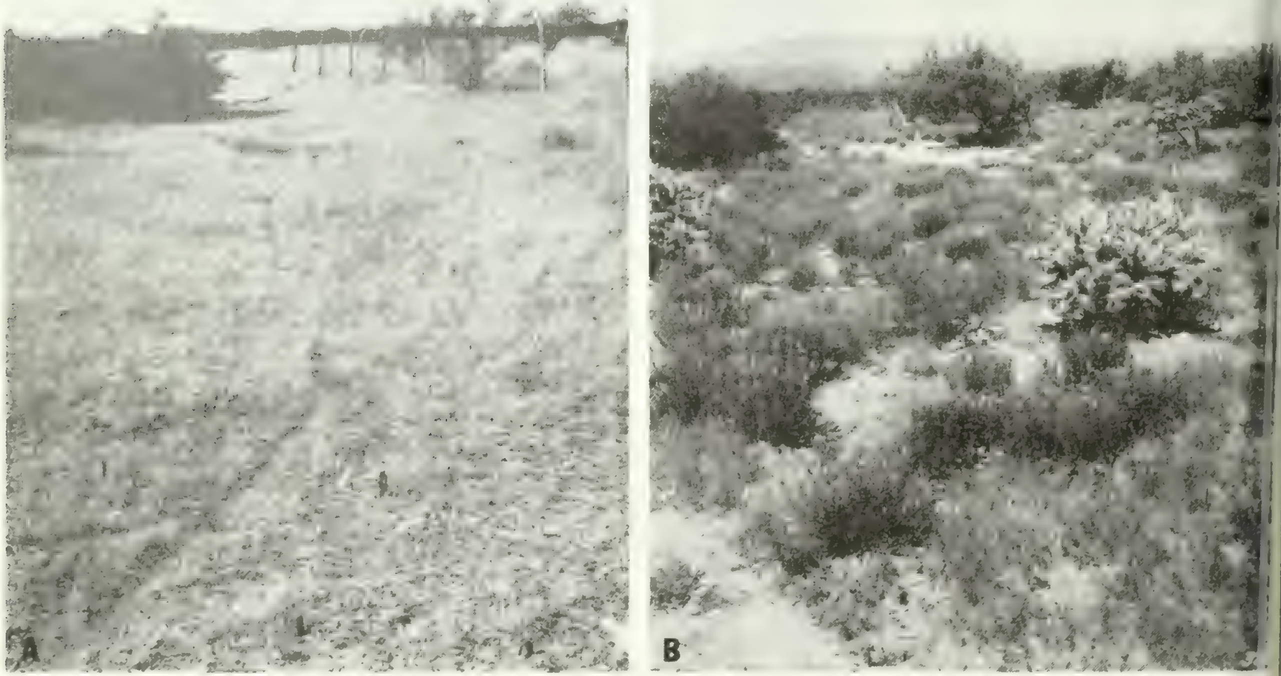

Figure 8.—As shrubs replace grasses, the range deteriorates:

A, in 1922 this spot at the edge of a mesquite stand had a good grass cover and few woody plants;

B, by 1935 burroweed, cholla, and new mesquites had almost replaced the grasses.

SOCIAL AND ECONOMIC FACTORS

Historical Development

The historical development of the western portion of the semidesert grass-shrub region is portrayed by Hastings and Turner (1965). They present the view that, even at the time cattlemen from the "East" occupied the region, conditions were not those of a stable, pristine climax of indefinite age. The Texas longhorns moved in only after the Indians, Spaniards, and Mexicans had left their imprints on the land.

Populations of Indians and native herbivores apparently waxed and waned in prehistoric times primarily in response to climatic factors. Cattle were introduced into southern Arizona soon after 1700 by Father Kino. Northern Mexico was probably fully stocked by cattle on Spanish ranches during the last quarter of the 18th century. Expansion of these Spanish ranching operations to the north probably reached its peak in southern Arizona in the 1820's and 1830's. Nearly all of the ranches established during this time were abandoned by 1846, leaving many cattle to run wild.

The number of cattle in the Arizona territory was reportedly only 5,000 in 1870. Rapid movements of cattle from Texas and Sonora into Arizona increased o an estimated 650,000 in 1885. The census of 1890 shows 1,095,000 range cattle in Arizona. By his time, many cattlemen realized that the ranges were overstocked. Following severe summer drought in 1891 and 1892, cattle losses from starvation were estimated to be from 50 to 75 percent by the late pring of 1893.

Hastings and Turner (1965) place the date for the beginning of the current arroyo cutting cycle in the Southwest, and for the initiation of dramatic changes in vegetation, at about 1890. They cite other reports to the effect that there have been earlier cycles of rroyo cutting, and argue that a warming and drying limatic trend from about 1875 to 1890 was a major actor contributing to this one. That the buildup of attle numbers in the 1880's was a strong contributng factor is unquestioned. Whether the shift to ridity postulated by Hastings and Turner would ave led to the dramatic change in vegetation and rroyo channel characteristics without grazing is ncertain.

Soon after the turn of the century, Wooton (1908), eporting on the condition of New Mexico ranges, tated that the range was run down and not as roductive as it once was. Wooton's explanation of he impact on unwise grazing was "Stock eat the aluable forage plants and leave the poor ones, thus iving the latter undue advantages in the struggle for xistence." . . . "Skinned ranges do not hold water; he runoff is greater and more rapid, tending to increase dryness, the cutting away of soil, and the drying up of springs and watercourses." Wooton attributed the poor condition of the range largely to the open range policy. He estimated the carrying capacity of the semidesert grass-shrub type to be 50 acres or more per head per year. Jardine and Hurtt (1917) estimated that the carrying capacity of the Jornada Experimental Range was 38 acres per head per year, and that the carrying capacity of outside range was about 50 acres.

In southern Arizona, Griffiths (1901) likewise found the ranges to be seriously depleted as a result of serious and prolonged overstocking due to the free range policy. He felt that the ranges might be improved by appropriate rest, but that in some cases seeding might be worthwhile or necessary. Three years later, he estimated that the carrying capacity of lands in Arizona ranged from 52 to 100 acres per cow (Griffiths 1904). In 1910, reporting changes on the Santa Rita Experimental Range (established in 1903), Griffiths felt that 3 years of rest apparently was sufficient to restore the range; that the best ranges on the Santa Rita might carry one animal per 20 acres; but that such areas were very limited.

Griffiths (1910) also reported a dramatic increase in mesquite, particularly at the upper elevations, and attributed the increase to protection from fire. By 1941 many acres of former grassland were fully occupied by mesquite (fig. 9). Griffiths (1910) reported that filaree was the only introduced plant that succeeded in seeding trials, and that the best way to improve the range was by proper protection from overgrazing. In Texas, Jared Smith (1899) after analyzing the opinions of 302 stockmen in 115 counties, estimated the average decrease in carrying capacity to be 40 percent in 82 counties; 19 counties reported improvement. Smith agreed with other writers in blaming the free-range policy for most of the decline. Too many cattle, the result of free-range policy, was also blamed by Thornber (1910) for the poor condition of Arizona ranges at that time.

Passage of the Taylor Grazing Act in 1934 brought 10,400,000 acres of semidesert grassland and 7,954,000 acres of southern desert shrub under federal supervision. The Taylor Grazing Act applied to all unallocated public domain. It provided for assignment of the land to individual stockmen, but did not include a strong administrative organization or adequate financing.

Current Situation

Many semidesert ranges have improved since the 1930's. Moderate stocking is more common, and many ranchers have improved their ranges by seeding, controlling shrubs, or periodic rest. Research results are publicized and put into practice

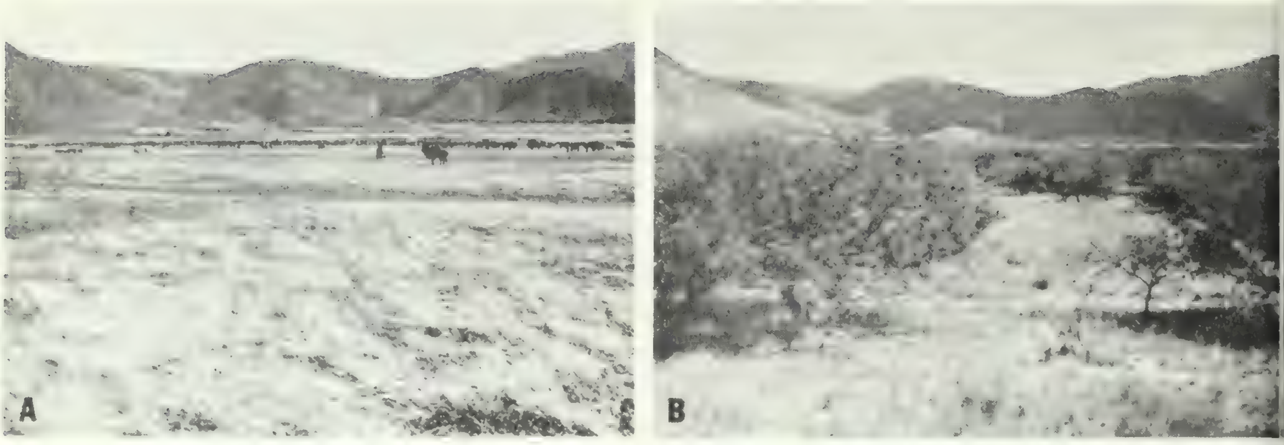

Figure 9.—Mesquite invasion in southern Arizona:

A, Griffiths photo in 1903 shows only widely scattered small mesquites.

B, repeat photo in 1941 shows a well developed mesquite stand.

through cooperative programs of the Soil Conservation Service, Forest Service, Bureau of Land Management, and Cooperative Extension Service, and through participation by ranchers in the Society for Range Management. Still, much of the semidesert grass-shrub range is producing far less than it could (fig. 10).

Semidesert ranges no longer are the almost exclusive province of ranches, range researchers, and public land administrators. Absentee owners, speculators, miners, sportsmen, and other recreationists are claiming an increasing voice in what happens on the land. Public concern about esthetics, habitat destruction, or the balance of nature has at times been great enough to halt projects to control shrubs or predators. Widespread concern about how public lands are managed has greatly increased planning costs of public land administration. To some extent it limits management choices for private landholders as well. As Byerly (1970) has indicated, we must now solve the problems of agricultural production with methods that are socially and economically acceptable. Environmental impact statements must now be included in proposals for major projects. Maximum sustained production of forage and livestock no longer is an adequate and complete range management objective.

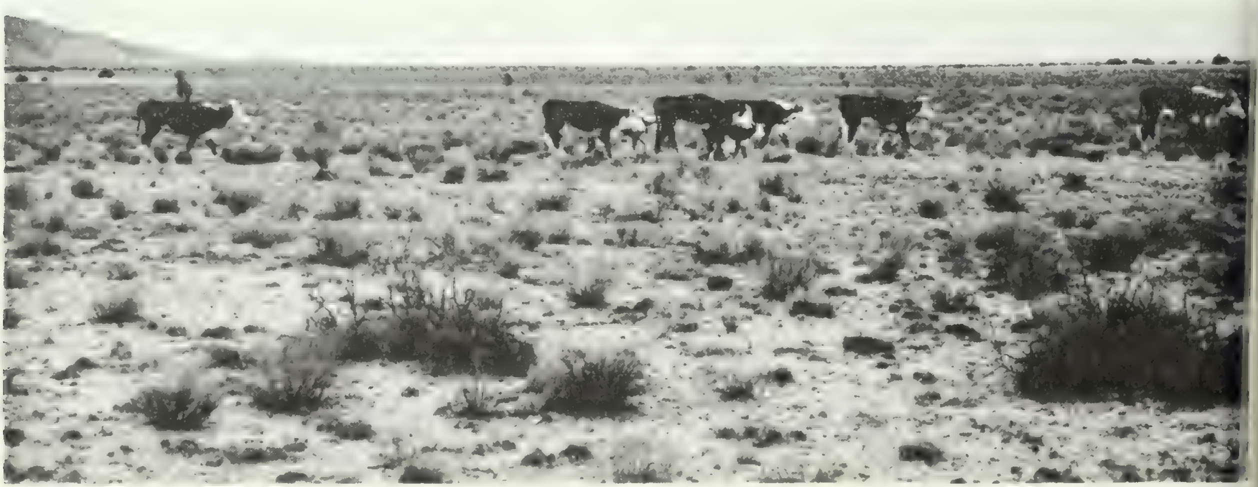

Figure 10.—This black grama range is producing far below potential. The black grama had been largely replaced by threeawns, mesquite, snakeweed, and annuals. Usable forage production here could at least be doubled.

Ranch Operations

The economics of ranching are changing greatly. Mont Saunderson (1939) reported the investment in land per animal unit to be from $71 to $108. Now we are in a land boom. A 1975 advertisement in the New Mexico Stockman listed ranches from $600 to $1,100 per animal unit. Gray (1970) reported investment per animal unit in ranches in the central mountains of New Mexico to be around $1,200. Ranch income has not increased correspondingly, however.

Except for 1972 and 1973,[3] prices for ranches and cattle in recent years have been such that net return to capital and management for Arizona cattle ranches was very low or even negative (Smith and Martin 1970). Frank Boice (1967) stated that a cow could not service a debt load much over $250. Why, then are ranches bought at $1,200 per animal unit? Andrews and Luden (1965) suggest that many purchases of rangeland are for purposes other than livestock production. Sargent (1957) listed 10 motives for owning ranch or farmland, and found that those who purchased land for motives other than agricultural production were in a stronger financial position than the rancher. William Martin (1966) has hypothesized that high ranch prices apparently are not based on the profit motive. Rather, ranch purchasers are simply paying for the privilege of being ranchers.

The future market in ranchland is uncertain. Smith and Martin (1970) report that a high percentage of Arizona ranchers are nearing retirement age. This means that large numbers of ranches will be coming on the market in the next 10 years or so. Only time will tell whether buyers will be plentiful enough and prosperous enough to maintain current prices. Meanwhile, the most economical way for ranchers to increase their livestock operations may be to increase forage production on the land they already have. Mesquite control, for example, can in many cases provide forage for additional cows at a cost of $200 to $300 per animal unit. Seeding and improved grazing systems are additional possibilities.

Despite the rather dismal economic status of ranching in recent decades, there seems little reason to believe that cattle ranching will cease or be greatly diminished anytime soon. No matter who owns or uses these grazing lands, cattle will continue to be a major source of regular income.

Energy Relations

Ours is an era of expressed concern about the energy requirements necessary to maintain our way of life. Agriculture has replaced the horse with the tractor, thereby making more food and fiber available for human consumption. The cost of this conversion, however, is that we now spend 10,000 calories of fossil fuel energy to produce 3,000 calories in crop products (Thomas 1971). Beef produced on the range, however, is derived almost entirely from solar energy. Fossil fuel expenditure is limited to that required to operate the rancher's car or pickup, that required by the farmer to grow supplemental feeds used by the rancher, and the relatively small amount that is used from time to time in the form of fuel for tractors or airplanes used to control brush, build ponds, or seed the range. Ecologically, range livestock production is more nearly in balance with nature than is mechanized agriculture.

RANGE MANAGEMENT PRACTICES

Perennial grasses provide the most important forage on grass-shrub ranges. Management therefore should be aimed at maintaining vigorous, productive grass stands. The objectives should be to increase good forage species and eliminate competing nonforage plants. Since forage production is more severely limited by lack of moisture than by any other single factor, every effort must be made to conserve and use as much moisture as possible on the site. A dense, well-dispersed stand of perennial grasses is the most effective kind of vegetation for utilizing available soil moisture before it evaporates following each rain.

Palatable shrubs and forbs contribute materially to the diets of animals on many semidesert ranges. Many of the forbs are annuals that provide high-quality forage for a brief time either during the spring or summer growing seasons. Shrubs provide relatively high-quality forage in winter or during dry periods when grass herbage is dry and frequently is deficient in essential nutrients. Generally speaking, cattle on ranges with a mixture of palatable shrubs and grasses require less supplementation in winter than do cattle on shrub-free grasslands. On ranges where wildlife is important, shrubs provide cover as well as forage, and management practices must meet the needs of shrubs as well as grasses.

Grass species vary greatly in palatability, and cattle tend to select and graze the preferred species closely. These plants lose vigor and die from excessive grazing and are replaced by species that are less palatable and/or more resistant to grazing. On the Santa Rita Experimental Range in Arizona, for example, species favored by moderate to light grazing include Arizona cottontop, bush muhly, black grama, sideoats grama, tall threeawns, and such less-abundant species as plains lovegrass and green sprangletop. On the other hand, species that are most abundant under continuous heavy grazing are curly mesquite, Rothrock grama, and slender grama.

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[3] *Higher cattle prices in 1972 and 1973 greatly increased ranch income in those years, but cattle prices in 974 dropped below the 1968-71 level.*

Obtaining Proper Grazing Use

Kind of Animal

Semidesert ranges are grazed primarily by cattle. At the eastern end of the semidesert area, sheep and/or goats are somtimes run with cattle to better utilize all classes of forage. There is substantial evidence from Merrill's (1954) work at Sonora, Texas, that sheep help keep the forbs in check, and goats help keep the shrub live oak and other relatively palatable shrubs from getting out of hand. Vegetation control exerted by sheep and goats therefore is a fringe benefit over and above the income from animal products. There is little evidence to suggest, however, that browsing by sheep or goats will materially reduce the growth and spread of mesquite, juniper, catclaw acacia, or creosotebush.

It appears that cattle are better suited than sheep or goats for most semidesert range. They require less attention, and compete less directly with wildlife for forage.

Additional information on the suitability of different kinds or classes of animals for semidesert range is desirable, but the need is not critical or urgent.

Number of Animals

The key indicator of proper stocking is the intensity of use. As a rule of thumb, the number of cattle grazed should be sufficient to utilize about 4 percent of the perennial grass herbage produced i an average year. This level of grazing will maintai good grass composition over most of the range. Eve at this average level of use the vegetation wher cattle naturally congregate will be grazed mor closely than is ideal, but severely overgrazed spot will be relatively small. Estimated average yearlon stocking rates (table 1) were developed on the Sant Rita Experimental Range by Reynolds and Marti (1968). These rates apply fairly well to the entir spectrum of southwestern ranges and range cond tions. They range from 13 to 2 acres per animal un month. These are average figures over a period years assuming yearlong grazing. The poorer range vary the most from year to year. In poor years the may produce no herbaceous forage.

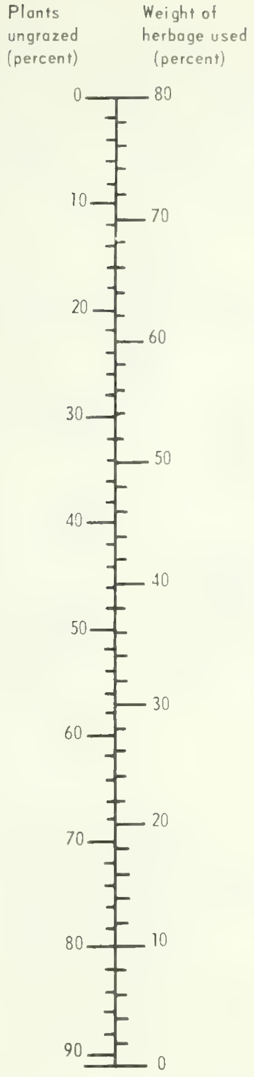
The stocking rates above assume that utilization perennial grasses over a period of years averag around 40 percent, but may range from as low as percent to as high as 60 percent in individual year A simple, practical, and inexpensive method f measuring utilization is to determine the percenta of grazed and ungrazed plants (Roach 1950). T relationship between percentage of herbage remov and number of plants ungrazed (fig. 11) is for mix species of perennial grasses on the Santa Ri Experimental Range. The relationship varies som what among species, but unless great precision needed it is suitable for most applications. As a ru of thumb, about half of the perennial grass plan should remain ungrazed in the average year (fig. 1

For various reasons, ranchers are tempted to sto on the heavy side of proper. First, perhaps, is t factor of attitude or image. The rancher vie himself as a cattleman—his standing among catt men and his self esteem are based to a degree

Table 1.--Estimated average yearlong stocking rate, by condition class, for semidesert grass-shru range (adapted from Reynolds and Martin 1968)

Elevation (Feet)	Precipitation	Range condition class					
		Very poor[1]		Poor and fair		Good and excellent	
	Inches	*Animals/ square mile*	*Acres/ animal*	*Animals/ square mile*	*Acres/ animal*	*Animals/ square mile*	*Acres/ animal*
High (4,000-5,000)	16+	<12	>50	15-18	35- 45	18-25	25- 35
Intermediate (3,300-4,000)	12-16	<6	>100	6-12	50-100	12-16	40- 5
Low (Less than 3,300)	<12	<4	>160	4- 6	100-160	6-10	60-10

[1] < signifies less than; > signifies more than.



igure 11.—Chart for approximating percent utilization by weight, when average percentage of ungrazed key species has been determined by survey.

he number of cattle he owns. Second, is the ifficulty of determining capacity when forage pro-uction varies greatly from year to year. Third, in the hort haul, a degree of overstocking almost always uts more money in the pocket. Up to a point, naximum ranch income in the short-run results from tocking rates that are too heavy for the good of the ange because they produce greater gains per acre.

Remedies for some of these inclinations seem bvious. The image factor, for example, requires hanging the rancher from a "cattleman" to a forage grower," and demoting the cow to the status f forage harvester and processor. A competent rage grower will not maintain more harvesters than re needed to gather and process his crop.

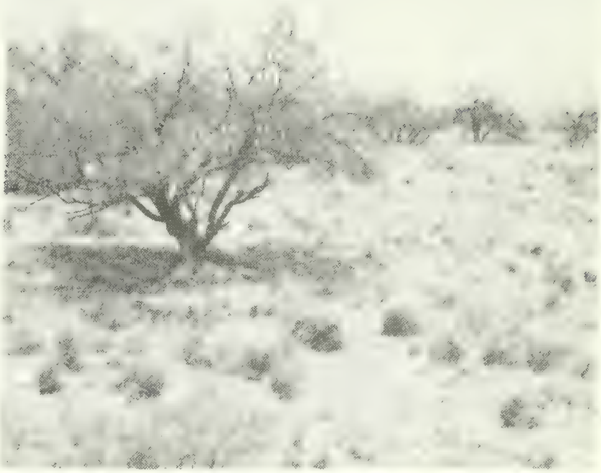
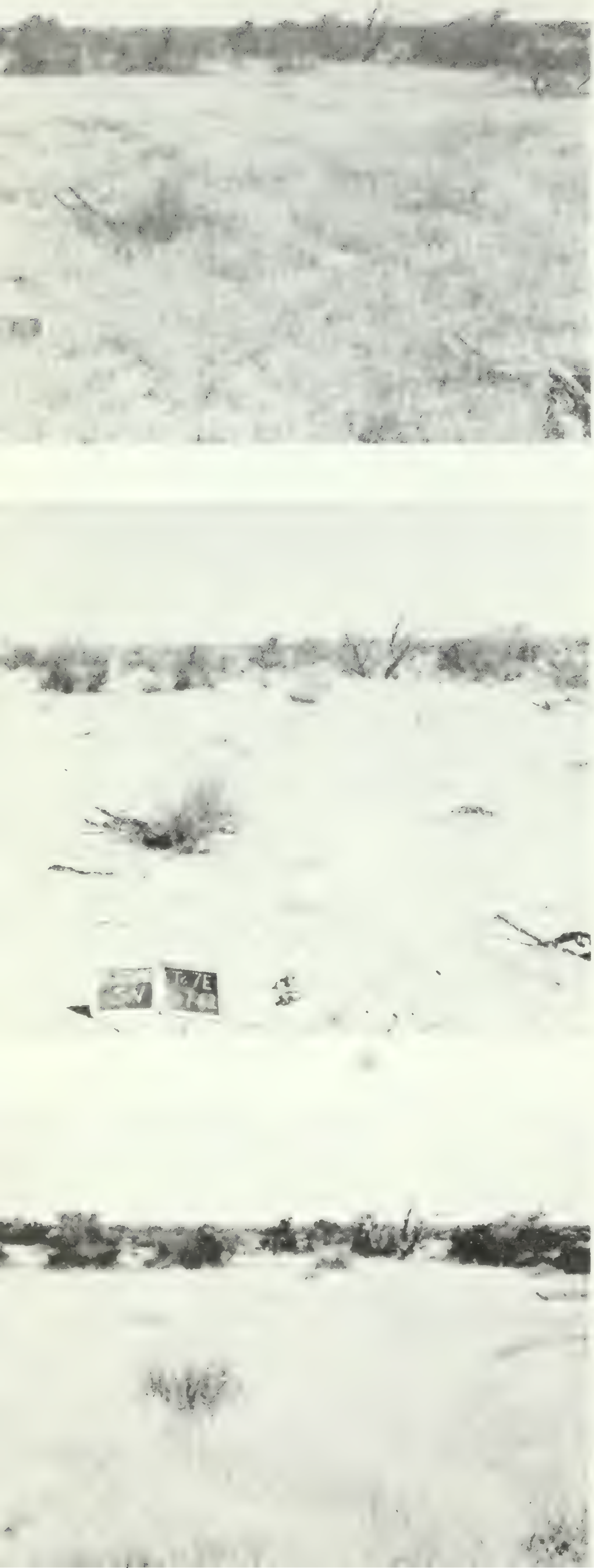


Figure 12.—Example of properly used range: average use at the end of June following a year of average forage production where average annual rainfall is 16 inches.

The second difficulty is harder to resolve. The carrying capacity of a range cannot be measured precisely. Forage production varies greatly from year to year as well as seasonally (figs. 13, 14). Even the quantity of usable forage at a given time can only be estimated. And the responses of forage plants to grazing depend not only on when and how closely the plant is grazed, but on how vigorous the plant is at the time and on how favorable the climate for recovery turns out to be. The forage requirements for range livestock also vary seasonally and are not precisely known. So the problem is to arrive at a stocking plan that meets the long-range needs of both plants and animals without imposing undue temporary hardship on either.

A fact of life to be faced in the fall of a drought year in the western half of the semidesert range is that substantial forage growth is not to be expected before mid-July of the next year. Also, it should be recognized that forage production cannot be high in the first growing season after drought because high yield requires two successive favorable growing periods. For example, Nelson (1934) reported that black grama increased or decreased in accordance with rainfall for the previous year, and Cable (1975) found that herbage production was strongly influenced by late summer rainfall in the previous year. Since the first expected period of rapid forage growth is at least 8 to 10 months away, and there is less than a 50 percent chance that the next year's forage crop will be as good as average, the reasonable decision following a summer drought is to cull more severely than usual.

Figure 13.—On low-elevation, low-rainfall ranges where annual grasses prevail, production of grass herbage can drop from (**A**) 655 pounds per acre one year to (**B**) 3 pounds the next, then shoot up to (**C**) almost 900 pounds a year later.



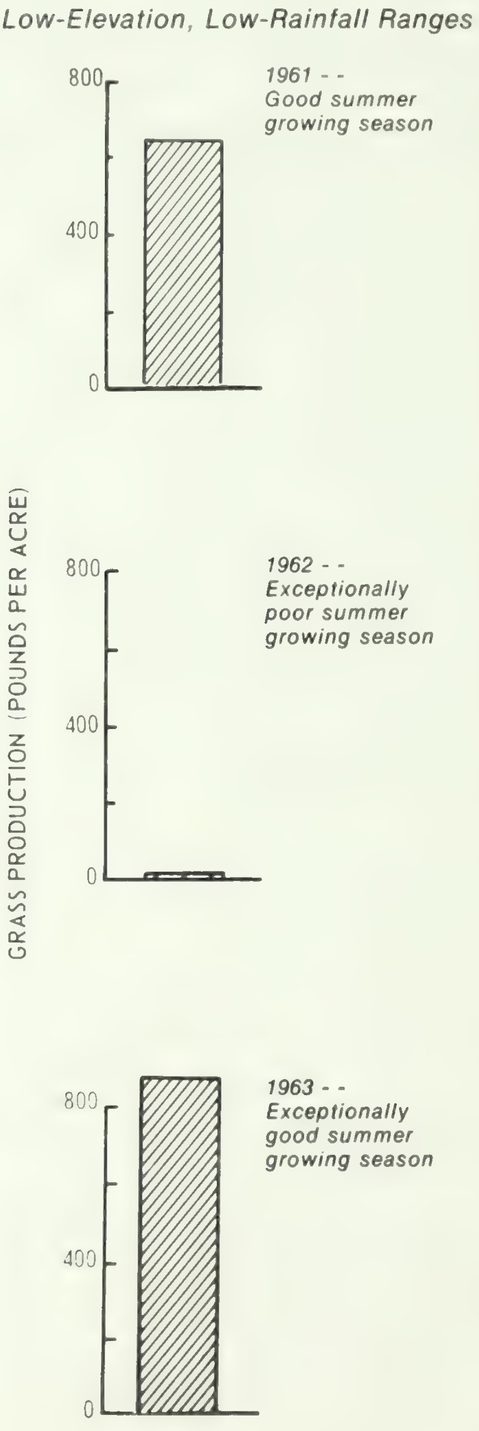
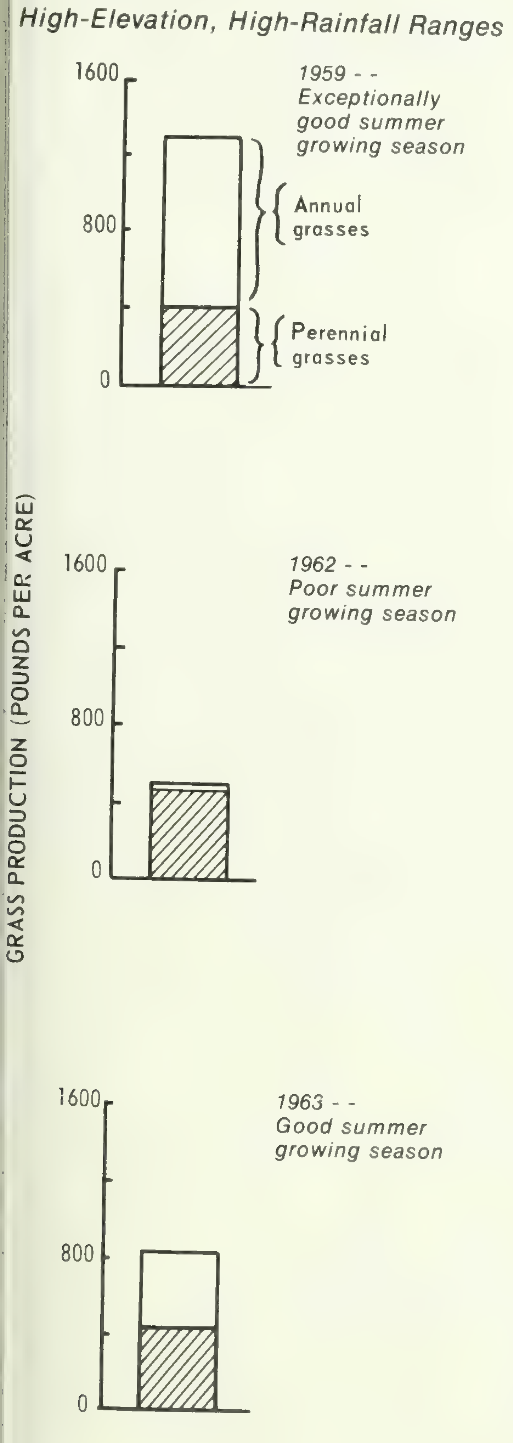


Figure 14.—On highly productive ranges, perennial grasses produce a modest yield of forage even in poor years. Annual grasses add substantially to the herbage supply only in years of moderate to high rainfall.



Nelson (1934) evaluated the impact of drought and grazing on black grama ranges in southern New Mexico. He found that the production of heavily overgrazed range declined 81 percent, compared with a decline of only 58 percent on conservatively grazed range.

There is some hope that usable formulas can be developed for estimating forage production from rainfall records. Cable (1975), for example, has found that perennial grass production in southern Arizona is strongly correlated with the product of certain portions of current and past summer rainfall. Perfection of such formulas would enable the rancher to estimate his forage crop with little effort and adjust animal numbers accordingly. Meanwhile, his best bet is to keep adjusting animal numbers until use on perennial grasses in an average year is about 40 percent. If this is done, the third problem—stocking too heavily in order to increase immediate income—will have been solved also.

Reliable procedures for determining appropriate stocking rates continue to be among the greatest needs of ranchers and public land administrators. This continues to be a problem of the highest priority. Aspects of the stocking rate problem that appear especially urgent are: (1) determining levels of stocking that leave the optimum amount of protective vegetation and litter, (2) determining appropriate intensities of use for systems of grazing other than continuous yearlong, and (3) identifying and evaluating beneficial effects of grazing.

Season of Grazing

Both the preferences of the cattle and the responses of plants must be considered in developing plans for seasonal grazing. Semidesert ranges traditionally have been grazed yearlong. Research and experience indicate that these ranges can be grazed at any time of year without serious detriment if the intensity of grazing is not too severe, and if periods of grazing alternate with suitable periods of rest.

On the Santa Rita Experimental Range, grazing November to February apparently has no detrimental effect, but either spring grazing (March to June) or summer grazing (July to October) can be detrimental if too severe or too frequent. During the summer rainy reason, perennial grasses grow rapidly enough to keep ahead of consumption if the stocking rate is moderate and rainfall is adequate. But favorite plants and preferred parts of the range are overgrazed and regrazed, even in average-to-good years. This kind of selective grazing is critical early in the spring when green forage is always scarce. It is during these periods of forage scarcity that selective grazing is most harmful.

Selective grazing is more serious on some ranges than on others. On flat ranges, for example, the tendency of cattle to graze off the last bite of grass near water before ranging farther is much less strong than on steep, rocky ranges. Kinds of forage make a difference too. For example, Cable and Martin (1975) found that the most influential factor affect ing the percent of forage used at a given location was the relative palatability of the forage. These result were obtained within 1 mile of water on moderatel sloping to rough ranges where the average annua rainfall is about 16 inches and the most common forage grasses are slender grama, sideoats grama Arizona cottontop, tall threeawns, and black grama Of these five major species, Arizona cottontop wa the most palatable, black grama the least. Thus yearlong grazing almost invariably results in exces sive use of Arizona cottontop.

A different situation prevails in New Mexico o range dominated by black grama. Herbel et a (1974) found that mesa dropseed and such forbs a leatherweed croton, woolly paperflower, spectacle pod, and Russianthistle would draw cattle out as fa as 3 miles from water at certain times of the yea thereby taking some of the grazing pressure off th black grama. In this case there are times when blac grama is less palatable than some of the forbs and short-lived grasses. When cattle switch to these alternate forages, black grama gets a break. Th extent to which alternate forages reduce the need fo planned rest on black grama range is uncertain.

Additional research is needed to find out how reduce the detrimental effects of grazing in th spring and during summer drought. The greatest need in this area is for basic information on t responses of the most important semidesert perenni grasses to drought and grazing. Arizona cottonto black grama, sideoats grama, blue grama, bu muhly, plains lovegrass, plains bristlegrass, tobosa curly mesquite, tall threeawns, alkali sacaton, a sand dropseed are some of the candidates for th kind of research. Because such information necessary to formulate sound grazing systems, th problem has high priority for research.

Grazing Systems

Yearlong grazing.—Continuous yearlong grazing the most common system on semidesert ranges. Th primary shortcoming of the method is that it leads excessive use in areas of concentration and was forage where cattle rarely graze. It also leads inequitable distribution of use among species w favorite species being grazed more closely and m often than those that are less palatable. Cool-sea grasses and palatable shrubs are almost alw grazed too closely. At a moderate stocking le continuous yearlong grazing does not impose ex sive grazing over an entire pasture during the summer growing season because only one-fifth of the year's grazing takes place in a period that produces 90 percent of the forage (Culley 1943). The problem is that the favorite parts of the pasture and the favorite plants are grazed first each summer. Much more critical is the spring growth period, when 10 percent or less of the forage is produced but previously grazed plants are regrazed as cattle search out the new green forage.

Several alternatives to continuous yearlong grazing have been tried. Many reports show less weight gain from complex systems than from continuous grazing. In west Texas, however, Waldrip et al. (1967) reported that two- and four-pasture rotation systems produced more and heavier calves than did continuous use. A four-pasture three-herd system that rests the range 4 months out of 16 has also produced favorable responses in both plants and animals at Sonora, Texas (Merrill 1954).

Many, if not most, of the complex grazing systems also have failed to improve the range. Many failed because the rest periods were too short, too infrequent, or at the wrong time to allow plants to recover from grazing. Other systems failed because stocking was too heavy or because some other basic principle of range management was ignored.

In some circumstances, a degree of summer deferment can be achieved by closing access to waters. On the Santa Rita Experimental Range, this method reduced use near water but only if average use for the entire pasture did not exceed about 40 percent and if the water was closed during the summer growing season (Martin and Ward 1970).

Grazing schedules that have not been noticeably superior to yearlong grazing (Martin 1973, Martin and Cable 1974, Martin and Ward, in press) include:

1. Rest November through April each year.
2. Rest May through October each year.
3. Rest November through February; 1 year in 3, 2 years in 3, 3 years in 4, or every year.
4. Rest March through June; 1 year in 3, 1 year in 2, 2 years in 3, or 3 years in 4.
5. Rest July through October; 1 year in 3, 1 year in 2, 2 years in 3, or 3 years in 4.
6. Rest March through October; 1 year in 3 or 1 year in 2.
7. Rest March through October—graze November through February—then rest July through June; 1 year in 2.

Obviously there are many alternatives to yearlong grazing, but only those that meet the needs of forage plants will improve the range. Four of the more promising alternatives are described in the following paragraphs.

Rest rotation.—The rest rotation grazing system advocated by Hormay (1970) is a departure from conventional systems of deferment and rotation. Rather than dividing the grazing or growing season artificially into two, three, or more parts and moving livestock by the calendar, the rest rotation system provides rest for specific purposes and for longer periods than under the more conventional methods. Also, the rest rotation system assumes that heavy grazing in periods of forage scarcity can be tolerated if forage plants have ample rest periods for recovery. This assumption has not been fully validated, even though Mueggler (1972) suggests that occasional heavy grazing under rest rotation grazing may be beneficial. The classic rest rotation plan is a five-pasture system with rest periods designed after each grazing for one of the following purposes:

1. To allow plants to make and store food and recover vigor.
2. To allow seed to ripen.
3. To allow seedlings to become established.
4. To allow litter to accumulate between plants.

As in the deferred and rotation system (Sampson 1913), grazing after seed ripening is assumed to aid in the establishment of new seedlings by trampling seed into the ground for more effective germination. The main principles of rest rotation can be built into four- or three-pasture grazing systems. Hormay suggests that pastures should be of about equal capacity. Rest rotation systems undoubtedly will benefit many semidesert ranges if the grazing schedules are properly meshed with growth periods.

High-intensity low-frequency grazing.—A relatively new rotation scheme, high-intensity low-frequency grazing, is currently being tested in Texas. The concept is similar to that of "short duration grazing" described by Goodloe (1969). In this system, all cattle in a set of several pastures graze one pasture at a time. The system is less formal than the Hormay system in that pastures need not be of equal capacity, and cattle are not moved on a prescribed schedule to meet specific objectives. Cattle are left in a pasture until the desired degree of use is obtained, then are moved to another. Heavy stocking for a short period reportedly results in more even utilization of the forage both from place to place and among species. Consequently, the favored forage plants have a better chance than under systems where cattle have an opportunity to be more selective. Rapid recovery of forage plants is the result of relatively long rest periods between short grazing periods. The high-intensity low-frequency system reduces labor costs because the cattle are all in one pasture. It provides opportunities for range improvement through brush control or seeding without fencing the project area.

Santa Rita three-pasture rotation.—Another system, now being tested on the Santa Rita Experimental Range, rests each range two-thirds of the time. Each unit in a three-pasture set is rested March through October 2 years out of 3. Winter grazing (November to February) is scheduled between the two successive March-October rest periods. Trampling in winter may help plant seeds, and grazing off the old herbage may give seedlings of intolerant species a better chance to become established. This schedule provides 12 months of rest immediately before each period of spring-summer grazing, and is expected to reduce the intensity of grazing and regrazing on favorite plants in the spring. This system is based on results on small plots where rest March through October 2 years out of 3 increased the density of perennial grass near water without controlling utilization (Martin 1973).

Apparent advantages of the system are: (1) The cost of handling cattle is reduced because only one-third of the pastures are used at a time. (2) Each year's forage crop is used from each pasture. (3) It provides opportunities for seeding or shrub control without fencing off the project areas. (4) The quality and quantity of forage from July through October, the period when cattle most consistently make gains, should be adequate because 90 percent of the year's forage is produced in this period.

This system is more formal than the high-intensity low-frequency system previously described, but departure from the schedule is permitted. The herd normally is moved twice (November 1 and March 1), but if forage in the grazed pasture is inadequate, cattle are moved ahead of time to the pasture next scheduled for grazing. A forage shortage therefore speeds up the cycle, but the normal schedule is resumed as soon as possible. On the other hand, a forage surplus may permit an extra rest period and/or an opportunity for brush control or seeding.

Schmutz three-pasture rotation.—Another three-pasture one-herd system for semidesert ranges is proposed by Schmutz (1973). In this system the year is divided into the same three 4-month periods: March-June, July-October, and November-February. A pasture is grazed July through October in its first year, March through June in its second year, and November through February in its third year. It differs from the system under test at the Santa Rita in that (1) no pasture is grazed continuously March through October, (2) 16 months' rest after summer grazing and 4 months' rest after winter or spring grazing is provided, and (3) the herd is moved three times a year (November 1, March 1, and July 1). This system deserves field evaluation.

Discussion.—Many ranchers are reluctant to change from yearlong grazing to a more complex system because they are not sure that the change will pay. On many ranges, for example, lack of water is an obstacle that must be overcome before complex grazing systems can be installed. If a pasture is watered by a spring or well that is barely adequate for the number of livestock the range will support on a yearlong basis, additional water must be developed before the pasture can be used in a system that requires doubling or tripling the stocking for a shorter period. Fences may have to be moved or new division fences built. Grazing systems also require extra cattle moves. Appropriate rotation systems offer compensating benefits, however, such as lower livestock handling costs that result from having cattle concentrated. They also offer the best insurance against future declines in range productivity.

Experience shows that complex grazing systems, even if well designed, do not always produce dramatic range improvement. Sampson (1951) concluded that regional and local conditions greatly influenced results from grazing systems, and that some form of rotational grazing was essential for bunchgrass ranges. Moderate seasonlong grazing produced greater livestock gains on sod-grass ranges without apparent injury to the vegetation, however.

A major difference between bunchgrass and sod-grass ranges is the way the forage stands are perpetuated. Bunchgrass ranges are maintained only if new plants become established fast enough to replace those that die. Sod-grass ranges perpetuate themselves vegetatively. Periodic rest to allow for seed production and establishment of seedlings is therefore a more evident need for bunchgrass ranges. These differences lead to arguments as to the importance of such factors as deferment until seed maturity and the role of grazing and trampling in planting grass seed.

A benefit that grazing systems offer on all types of range is periodic rest for overgrazed areas and overgrazed species. In the long run, this may outweigh the short-run advantage in animal gains that are so frequently reported for continuous grazing.

Finally, climatic events can override the effects of any grazing treatment. Severe and prolonged drought can temporarily reduce perennial grass stands under any grazing system. However, systems of grazing that meet the growth requirements of forage plants reduce the impact of drought on perennial grasses, and increase the rate of recovery afterwards. Improvement in perennial grass stands can be rapid, but rapid increases come only when the amount and distribution of rainfall is favorable Generally speaking, two summers of average o above rainfall in succession are required for dramatic improvement in perennial grass stands.

Summary.—Effective grazing systems require resting each part of the range a substantial part (a much as two-thirds) of the time. Rest periods no only must meet the growth requirements of important forage plants, but must also offset the natural tendency of cattle to regraze their favorite plants. Thus a major reason for rest periods on semidesert range is to even out utilization from place to place and among species. Systems must be designed to meet the needs of plants without unduly neglecting the animal's persistent need for ample high-quality forage. Four systems that appear to meet these specifications are: (1) rest rotation grazing, (2) high-intensity low-frequency grazing, (3) the Santa Rita three-pasture rotation, and (4) the Schmutz three-pasture rotation.

Additional research on grazing systems is urgently needed. Good systems, which could permit range improvement without severe reductions in cattle numbers, would remove a major barrier to range improvement. The first priority for research in this area is to pilot test promising systems such as those listed above. A test of system "3" is in progress on the Santa Rita Experimental Range. Tests on other forage types and conditions are needed.

Factors Affecting Forage Production

Rainfall

Herbage production of perennial grasses on a given range unit varies greatly from year to year, depending on the amount and distribution of rainfall. Herbel[4] reports yields as high as 800 pounds per acre on upland sites and 3,500 pounds per acre on flood plain sites in New Mexico where average rainfall is only 9 inches. In the 10- to 12-inch rainfall zone in southern Arizona, average herbage production of annual and perennial grasses combined over an entire pasture may range from as little as 5 pounds per acre in a dry year to 250 pounds in favorable years (fig. 15). Where rainfall and growing conditions are better, the year-to-year range in production may be from 300 to 1,200 pounds per acre (fig. 16). Over a period of years, however, average summer rainfall strongly affects the density and species composition of perennial grass stands, and thereby establishes the average productivity level. On the Santa Rita Experimental Range, where average summer rainfall from 1954 to 1968 ranged from 7.4 inches in the driest pasture to 10.8 on the wettest, average perennial grass yields ranged from 17 to 498 pounds per acre, respectively. Differences in average summer rainfall account for 86 percent of the average difference among units in perennial grass yields. On the average, each inch of average summer rainfall increased perennial grass production about 134 pounds per acre (fig. 17).

On a given site, the yield of annual grasses in different years is strongly and positively related to the amount of summer rainfall. On the other hand, ranges with higher average rainfall may produce less annual grass than low rainfall ranges. On the 16 Santa Rita pastures, for example, the average yield of annual grasses from 1954 to 1968 was less with 11.4 inches summer rainfall than with 7.4 inches. Differences in average summer rainfall accounted for only 2 percent of the differences among sites in production of annual grasses. Average yields of annual grasses apparently are more strongly affected by differences in the amount of competing perennial vegetation than by differences in average rainfall.

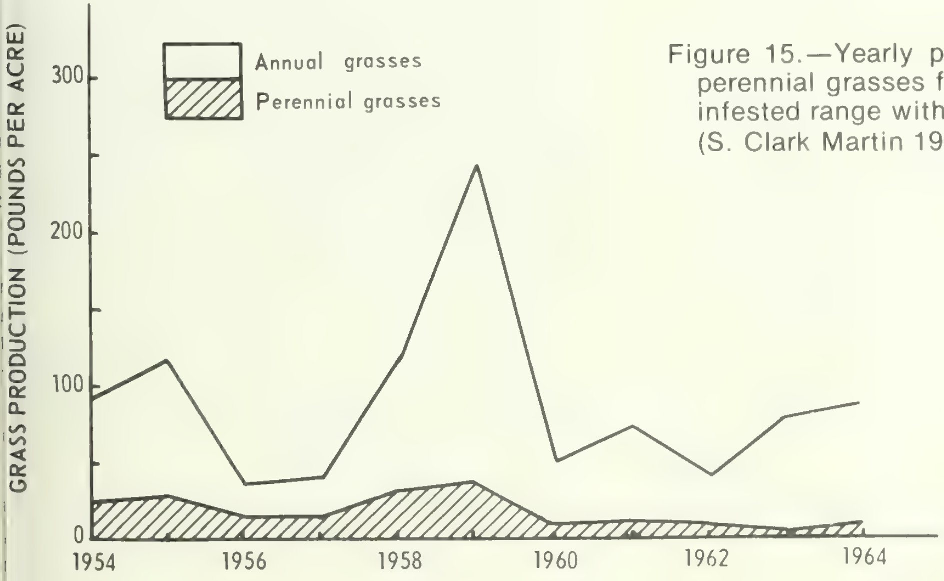


Figure 15.—Yearly production of annual and perennial grasses for a 5,000-acre mesquite-infested range with 12 inches annual rainfall (S. Clark Martin 1966).

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[4] *Personal communication from Carlton H. Herbel, January 28, 1975.*

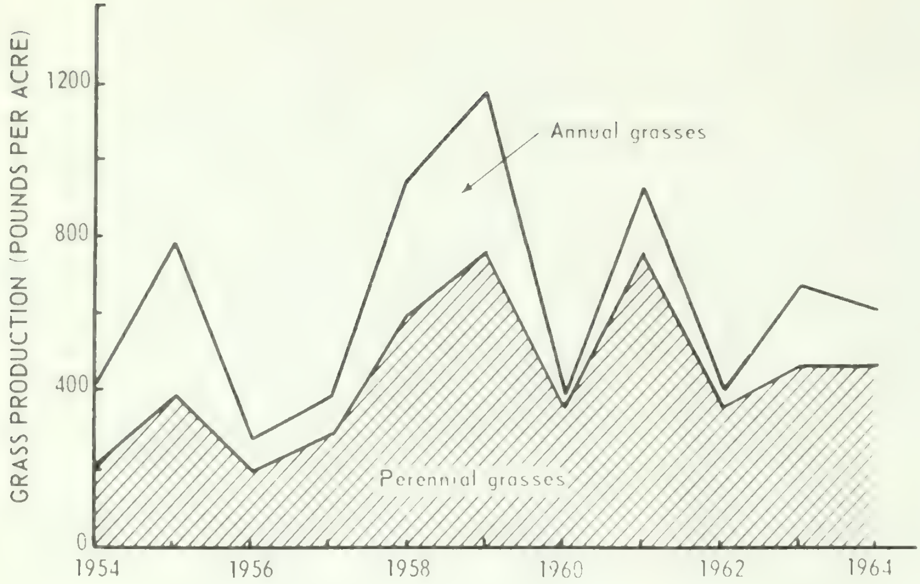

Figure 16.—Yearly production of annual and perennial grasses under a scattered stand of mesquite with 16 inches average annual rainfall (S. Clark Martin 1966).

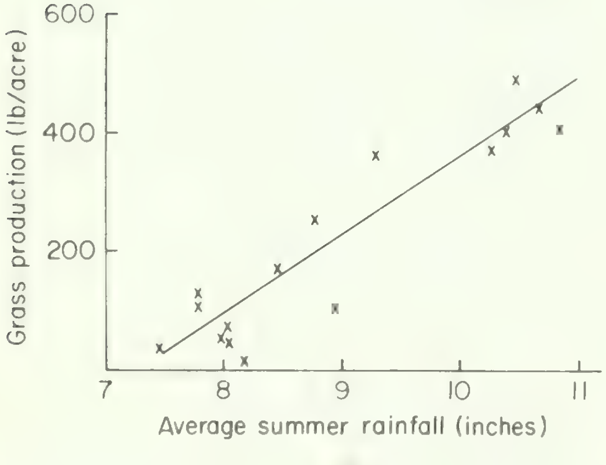

Figure 17.—Relation between average June-September rainfall (inches) and average perennial grass production per acre (pounds) from 1954 through 1968 for 16 pastures on the Santa Rita Experimental Range.

Range Condition, Grazing, and Drought

Ranges in excellent condition support a good mixture of the taller perennial grasses such as Arizona cottontop and sideoats grama. Plants are vigorous and provide a good cover of living and dead material. Low-growing species such as curly mesquite and sprucetop grama, short-lived perennials such as Rothrock grama, and annual grasses are minor forage components.

On the ranges in poor condition, the talle perennial grasses are limited to beneath the crowns of shrubs, or to exceptionally favorable or inaccessible sites. Even the low-growing perennials ar not producing in the open. Herbage is compose mainly of annuals and short-lived perennials. Wood plants may form the dominant aspect and the soil poorly covered with living or dead material.

Droughts, particularly of three or more consecutive years, can change species composition, vegetation cover, and herbage production, and can reduce range condition seriously despite past or present grazing management. Recovery of ranges from drought, however, is much more rapid on ranges that are moderately grazed than on those that have been overgrazed (Paulsen and Ares 1962). In fact, moderately grazed ranges recover even faster than ranges under complete protection. Thus, grazing can b beneficial to perennial grass stands. But the beneficial effects of grazing have received little research attention.

Site Potential

The incentive to improve semidesert ranges limited by their inherently low productivity. T often, however, the potential productivity of su ranges is not known and probably is underestimate The problem is especially acute because examples ranges that are producing maximum or ne maximum yields of forage for the site often are n available. To underestimate the productivity of the range is to discount the value of returns to be gained by improvement. Thus, potential productivity, like carrying capacity, is basic to management. The development of site potential standards is a high priority job. Such standards will give the public land administrator and the rancher realistic guides as to how well they are doing and how far they have yet to go.

First priority for research on production potential is to develop readily comprehensible standards of productivity for major semidesert ecosystems. For bunchgrass ranges the measure could be number, and species, of perennial grass plants per unit area. One desirable perennial grass plant per square foot, for example, might constitute a full stand for a given combination of soil precipitation, elevation, slope, and exposure. If the existing stand on such a site is only 1 plant per 10 square feet, or if the species present are poor in quality, the opportunity for improvement is evident.

Seeding

Some ranges are so seriously deteriorated that native grass will not recover in a reasonable time. Also, there are localized stock concentration areas on nearly all ranges where the native grass stand has been depleted. Seeding to exotic species sometimes can provide more and better quality forage in the early spring. Thus seeding can simply provide more forage, or it can provide forage of higher quality at a critical time of year.

Reliable seeding methods are known for the better sites on grass-shrub ranges (Anderson et al. 1953). Fairly level sites with deep, fertile, medium-textured soils are best for seeding. Herbel et al. (1973) reported good success seeding ranges receiving 9 inches of rainfall in New Mexico. In Arizona, seeding is not generally recommended where annual rainfall is less than 11 inches. If stands of mesquite, cactus, or burroweed are moderate to dense they should be controlled before seeding. Grazing of seeded areas should be closely controlled until the stand is well established.

The best species for seeding vary with the site. Above 4,000 feet and 14 inches of annual rainfall, Lehmann and Boer lovegrasses have been the most consistently successful. Blue grama, Arizona cottonop, and black grama are also good species, but are ifficult to establish. There are no commercial seed ources for the last two species. On upland sites in Arizona, where annual rainfall averages less than 13 inches, only Lehmann lovegrass has been established consistently. On bottomland sites or soils where moisture accumulates, blue panicum, Johnsongrass, Lehmann lovegrass, and Boer lovegrass grow well.

Good seedbed preparation is essential for success. The main purposes of seedbed preparation are to remove competing vegetation, cover seed, and promote moisture penetration. The eccentric disk and the intermediate pitter meet the objectives. Contour furrowing and ripping have also given good results. The recommended soil covering for seed is 1/8 inch for small-seeded species such as Lehmann lovegrass, and 1 inch for large-seeded species. A cultipacker seeder has proved best for covering small seeds. Larger seeds are best planted with a drill.

May and June just prior to the summer rains are the best months for planting. New stands should not be grazed until the second grazing season, or until seed has been produced. Once seeded grasses are established, the proper degree and season of use should be observed. Natural concentration areas for cattle cannot be successfully seeded to highly palatable species under continuous grazing. Rodent and insect control are sometimes necessary also.

Seeding where annual precipitation is less than 12 or 13 inches is risky, but the chances for success can be greatly enhanced by seeding in pits or by other soil treatments that increase infiltration or surface water. In a variety of tests, intermediate pits (basins approximately 5 feet square) have been more successful than conventional cut-away disk pits for establishing and maintaining stands of such species as Lehmann lovegrass and buffelgrass (Slayback and Cable 1970, Slayback and Renney 1972). Some means of collecting or concentrating water is especially important where annual rainfall is 10 inches or less.

Distribution of pelleted seed by airplane has been tested extensively with negative results. Clay pellets containing seed do not penetrate the soil on dry, unplowed range. The clay pellets dissolve quickly in the rain, leaving the seed perched somewhat above the soil surface on what remains of the melted pellet. If fertilizer is included in the pellet, it may decrease germination or it may cause the roots of the germinating seedling to concentrate near the surface and be especially susceptible to drought. The present state of the art is such that pellet seeding by airplane simply does not work (Hull et al. 1963, Jordan 1967, Chadwick et al. 1969).

At present, the expense and low probability of success is such that range seeding should be limited to sites where: (1) prospects for success are most promising, (2) the remnant stand of perennial grasses is so depleted that natural recovery with improved grazing management would be extremely slow, (3) competing vegetation is not excessive, and (4) grazing can be controlled. Adapted species, and approved methods of ground preparation and seeding should be used. Pitting, mulching, shrub removal, and rodent control should be employed if needed. Generally speaking, ranges should be seeded only if they will not respond fairly quickly to improved grazing management.

Seeding research should continue, but ranks lower in priority than grazing management. The rationale is that grass stands usually cannot be established by seeding where the native perennial grasses were driven out by the prevailing system of grazing.

Additional research is needed to develop and test pitting equipment that will enhance the chances of success where annual rainfall is less than 12 inches.

Plant Control

Good grazing management helps maintain vigorous stands of perennial forage grasses. Although a dense grass cover reduces the rate of increase of aggressive shrubs, even the best management will not keep these shrubs from eventually taking over many sites. On such ranges, persistent effort is required to prevent the development of moderate to dense stands of undesirable shrubs.

Mesquite

Mesquite invasion is considered detrimental throughout the semidesert range area. The first objection to mesquite is that it reduces the density and herbage yield of grasses (fig. 18). Mesquite foliage is used by livestock to some degree, and the flowers and fruits are high-quality forage, but forage production by mesquite does not compensate for the decline in grass production as mesquite becomes thicker. McGinnies and Arnold (1939) found that mesquite requires three to four times as much water to produce a unit of dry matter as do native perennial grasses. Even moderate stands (as few as 25 trees per acre in Arizona, for example) may cut herbage production in half. By reducing grass density, mesquite also induces or accelerates sheet and gully erosion. The lateral roots of mesquite remove moisture from the soil between the trees as well as beneath them. Wind tends to sweep litte and topsoil from the relatively bare areas between the trees and deposit it under the mesquite crowns. The net result is that growing conditions between trees become increasingly difficult and erosion accelerates

Mesquite is also objectionable because it increase the cost and difficulty of handling range cattle. A the cost of range labor increases, this factor become increasingly important.

Several factors have contributed to mesquite increases on semidesert range. Range livestock have contributed both directly and indirectly. By consuming mesquite beans, many of which pass through the digestive tract of a cow, cattle have spread mesquite seeds throughout the grazed area. This i only one reason why mesquite stands usually are heaviest where cattle naturally congregate. Cattle have contributed indirectly to the spread of mesquite by overgrazing and weakening the stands of perennial grasses. Vigorous perennial grasses compete strongly with mesquite seedlings. Experiments on the Santa Rita Experimental Range show that 16 times as many mesquite seedlings were established on bare areas as in vigorous stands of perennial grasses (Glendening and Paulsen 1955). Grazing also may have contributed to the spread of mesquite by reducing the amount of fuel for and the incidence of range fires.

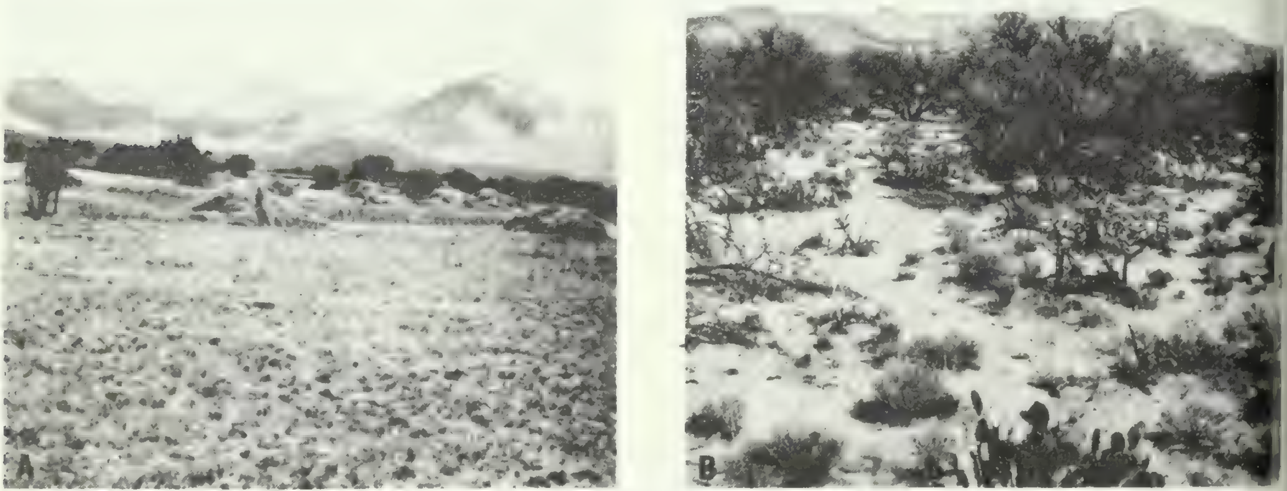

Figure 18.—Grass cover declines as mesquite increases:

A, view of native grass haying operations in 1903;

B, same site in 1964.

Mesquite-infested ranges can be restored to full productivity only if the mesquite is removed. Grass response following removal of moderate to dense stands of mesquite is excellent on sites with more than 8 inches summer rainfall and a good perennial grass remnant (fig. 19). A variety of mesquite control methods have been developed. No method so far developed is completely satisfactory, and each is peculiarly adapted to rather specific situations. Available methods include: (1) hand grubbing of mesquite seedlings, (2) individual tree treatment with diesel oil or with diesel oil containing herbicides, (3) application of granular herbicides to the soil around trees, (4) aerial spraying with herbicides, (5) individual tree dozing, (6) cabling or chaining, (7) roller chopping, (8) root plowing, and (9) prescribed burning.

Hand grubbing, which is effective for plants up to 1 inch in diameter at the groundline, is best for early invasion stands or colonies of small mesquites on relatively rock-free soils. In Arizona, the best time for grubbing is in the late spring when mesquite plants are green and easy to see in the dormant dry grasses. Grubbing is a labor-intensive method. It will not pay immediate returns on the investment because the removal of small seedlings does not increase forage production perceptably. Economically, grubbing must be justified as preventive maintenance—insurance against future production decline.

Diesel oil, like grubbing, requires so much labor that it is suitable mainly for small areas where mesquite control is especially needed. The method consists of spraying diesel oil against the trunk of the tree at groundline. Oil must saturate the bark on all sides of the stem and in the crotches. A gallon of diesel oil will treat four to eight trees. Mesquites that branch at or above groundline and have no more than five stems can be killed. Diesel oil fortified with 2,4,5-T is somewhat more effective than straight diesel oil, but the added cost is not usually justified. Diesel oil is not suitable for "dune" or "running" mesquite, nor is it suitable for use on flood plains where the bud zone has been buried beneath several inches of silt. Oil can be applied any time of year with kills up to about 90 percent, but cool-season treatments give slightly higher kills, and labor is somewhat more efficient when the weather is not too hot. Diesel oil, if properly applied, will kill either trees or stumps.

Immediate and often dramatic increases in forage production are obtained by killing moderate to dense stands of mesquites if there is a remnant of perennial grass.

Individual mesquites can also be killed by applying granular herbicides to the soil around the base of the trees. Monuron, fenuron, and karbutilate are effective when properly used. The advantage these herbicides have over diesel oil is that they are effective against any growth form of mesquite. One disadvantage of these materials, and others still under test, is that they kill a larger spot of grass at each tree than is killed by the diesel oil method. Other disadvantages include: (1) their relatively high cost, (2) unresolved questions about their total impact on the environment, and (3) legal restrictions (karbutilate, for example, has not yet been registered for use on rangelands).

For extensive control, application of herbicides by air is promising. Low-volatile esters of 2,4,5-T, when applied 2 years in succession and at the right time,

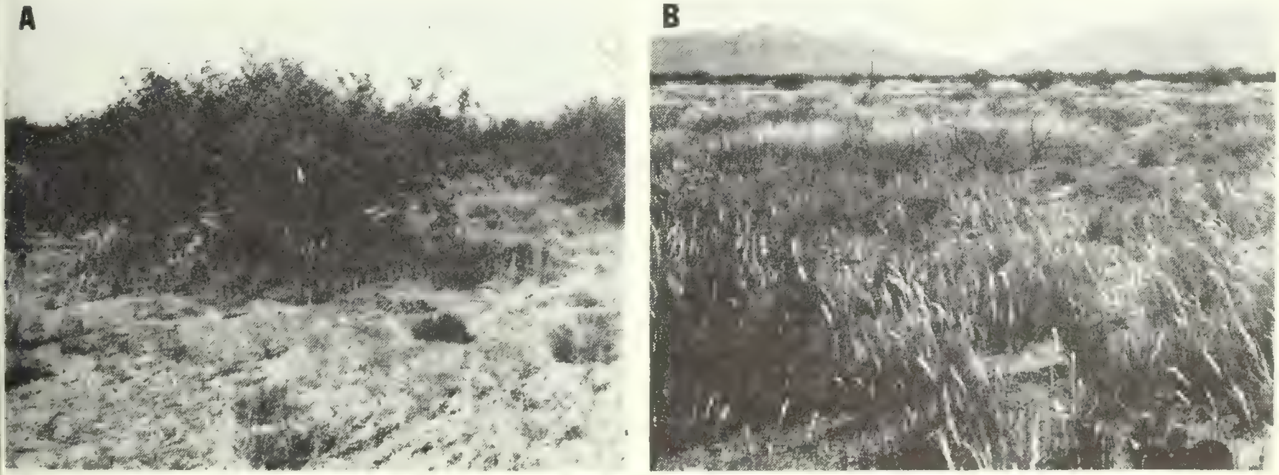

Figure 19.—Recovery of perennial grasses following mesquite removal:
A, sparse growth of grasses in undisturbed stand of mesquite;
B, adjacent mesquite-free plot produced an abundant forage crop composed mainly of Arizona cottontop and other native grasses.

provide effective control. Addition of picloram or other substances to 2,4,5-T has enhanced the kill in some experiments, but results have not been consistent.

Aerial applications of 2,4,5-T rarely kill more than 50 or 60 percent of the trees outright, but effective applications usually kill 90 percent or more of the top wood and markedly increase perennial grass production. Regrowth of mesquite after aerial spraying is relatively slow. On the Santa Rita Experimental Range, for example, mesquite control in 1954 and 1955 was still providing increased forage production in 1974. Greater increases in forage production could still be obtained by spraying a new area than by respraying the tract that was first sprayed 20 years before.

Aerial spraying leaves the top wood standing. Although the standing dead trees are esthetically displeasing, reduce visibility, and add to the difficulty of working cattle, they may provide some wildlife benefits.

Because the critical time for spraying mesquite with 2,4,5-T usually does not coincide with periods of active growth for other plants, the damage to species other than mesquite usually is negligible. Grasses are not visibly damaged, nor is there evidence to indicate that 2,4,5-T has been seriously detrimental directly to animals. The major impact on small animal populations probably results from changes in vegetation. Animals that do best in relatively sparse stands of grasses mixed with shrubs undoubtedly are affected adversely. Grassland species, on the other hand, should benefit. Since spraying does not result in 100 percent kill, sprouts from treated trees provide adequate mesquite foliage for browsing animals. On the other hand, spraying does stop production of flowers and fruits for several years. Until the impact of 2,4,5-T and related herbicides on the environment has been more completely assessed, these materials should be used only if the proposed use is approved by the appropriate pesticide control authorities.

Individual tree dozing is a good method for removing scattered stands of mesquite. It is effective on all growth forms and at any time of year, except that small seedlings are likely to be overlooked. When carefully done, bulldozing kills a high percentage of the mesquite and has the advantage that the stumps are removed and the trees are knocked down. With little extra expense, the uprooted trees can sometimes be pushed into arroyos, leaving the bulk of the area free of obstructions. Increases in herbage production following bulldozing depend largely on the degree of release obtained and on the ability of the remnant grass to respond. Bulldozing is more acceptable than chemical control in some areas because it does not introduce herbicides into the environment.

Two tractors dragging a cable or anchor chain between them can be used to knock down either dead or live mesquite trees of almost any size. Cabling in both directions will uproot most trees that have stems stiff enough to flip out the root systems. The cable or chain will simply slide over smaller trees (up to about 2 inches in diameter) and thorny shrubs such as catclaw acacia and wait-a-bit without damaging them seriously. Areas with moderate to heavy densities of these thorny shrubs probably should not be chained, as they tend to increase and become more vigorous after the mesquite overstory is removed. Thus a major disadvantage of cabling or chaining is that it usually results in rapid regrowth of sprouts from smaller trees.

Cabling knocks down not only the mesquite but other kinds of brush as well, and thereby provides an uninterrupted view. This has a real advantage from the standpoint of handling livestock. The major disadvantage, as previously indicated, is the low percentage kill, particularly on younger trees and shrubby understory species. Cabling must always be followed by other control measures. Spraying individual sprouts with herbicides, aerial application of herbicides, and burning are possible maintenance measures.

In dense stands of mature tree-like mesquite, the percentage kill by cabling may be about the same as with aerial spraying with 2,4,5-T. Spraying usually costs less than cabling, but it does not immediately provide a brush-free aspect. Followup is required in either case, but when all things are considered, cabling often is the better choice for cattle ranges infested with tree forms of mesquite.

Cabling is not effective on the low-growing, many-stemmed growth form of mesquite. On sandy soils where the many-stemmed mesquite forms dunes, cabling disturbs the soil too much and leads to excessive wind erosion. For mature dune-type mesquites, aerial spraying is preferable to mechanical control.

Huge roller choppers completely smash down all woody vegetation and provide a clear view, as does cabling or chaining. In fact, chopping may provide an even more uncluttered view because it does not leave the brush in piles as chaining or cabling sometimes does. Percent mesquite kill by chopping probably is no greater than with cabling, so followup measures are needed to maintain a brush-free aspect. Chopping and cabling do not destroy remnant stands of perennial grasses, although some plants are killed.

Although root plowing is the most destructive mechanical method of removing mesquite, it is also the most effective, because it uproots all plants in the area. Plants that survive are mainly those at the edge of a swath that are not completely severed by the blade. Small plants that are cut off but not flipped out also may survive, especially if the soi becomes wet soon after plowing. Root plowing destroys or seriously disturbs all vegetation including the perennial grasses. Therefore, seeding at the time of plowing is usually essential for the prompt reestablishment of a forage stand. However, Mathis et al. (1971) reported that herbage production 5 years after root plowing was lower on seeded range than on range that was not seeded.

Prescribed burning can rarely be used to control moderate to dense mesquite stands because such stands seldom produce enough fuel to carry a fire. A hot fire in June may topkill almost all small mesquites (up to ½ inch in stem diameter at groundlines) and kill about 50 percent of them outright (Glendening and Paulsen 1955), but very few trees larger than 4 inches in basal stem diameter are killed. The only place for prescribed burning in mature mesquite stands, therefore, is following some other method that has seriously weakened or killed the original trees. Once the original stand has been controlled by mechanical or chemical methods and a stand of grasses has become reestablished, periodic burning may be useful for controlling reinvasion and regrowth. Burning at suitable intervals will kill small plants back to the groundline periodically, and keep most of them from maturing and producing seed.

Ecologically, burning is not necessarily cheap. Fires that will kill mesquite will also kill grasses. Burning studies on the Santa Rita Experimental Range show that Santa Rita threeawn is not seriously damaged by fire, but that tall threeawns are. The difference apparently results because Santa Rita threeawn is randomly disturbed, mostly in the openings between shrubs, whereas tall threeawns grow mainly in shrub crowns where they are subjected to greater heat as the shrubs burn. Also, Santa Rita threeawn remains green at the base while tall threeawns dry to the groundline, thereby providing fuel for their own destruction. Unfortunately, many of our better long-lived grasses are severely damaged by fire and are very slow to recover. A June fire, for example, killed 90 percent of the black grama, compared to less than 50 percent of the mesquite (Cable 1965). In this case, fire killed almost all of the Lehmann lovegrass plants, but a new stand became established from seed during the summer immediately following the burn. Obviously, burning favors species that can survive a fire or quickly reproduce themselves from seed. Our best forage species are deficient in these attributes. A fire that kills 90 percent of the grass but only from 10 to 50 percent of the mesquite may not be desirable.

Creosotebush

Creosotebush occupies vast areas of the more arid semidesert region. Gardner (1951) reported that creosotebush has occupied much former grassland in New Mexico since 1850. Its grazing value is nil, and herbage production in moderate to dense stands of creosotebush is negligible. Some ecologists believe that creosotebush even has the ability to replace mesquite on areas that formerly were grassland.[6] Since creosotebush occupies ranges with relatively low potential, the response of perennial grasses to removal of creosotebush often is not striking. Grass stands where creosotebush predominates usually are so sparse that the cost of high-risk seeding must be added to those of shrub control. Therefore, even though responses may sometimes be dramatic, control of creosotebush is not often economically feasible.

Because of the economics involved, less work has been done on control methods for creosotebush than for mesquite. Creosotebush is relatively resistant to aerial applications of most herbicides. It is a vigorous crown sprouter and its stems are too flexible for effective chaining or cabling. Modified chains such as the Dixie sager may have possibilities. Root plowing is effective, but is often too expensive to be justified. Abernathy and Herbel (1973) report that shrub control, basin pitting, and seeding with a machine that does all three jobs at one pass will pay on selected creosotebush sites in southern New Mexico. A positive feature is that fourwing saltbush is often found growing intermingled with creosotebush. On such areas, removal of the creosotebush sometimes results in a good stand of fourwing saltbush, a much more valuable shrub, after a few years.

Recent work at the University of Arizona indicates that creosotebush (particularly young plants) is susceptible to fire (White 1968). Fire cannot be used in dense mature stands of creosotebush, however, because they rarely if ever provide enough herbaceous fuel to carry a fire. One possibility is to use fire following other treatments. Once the creosotebush has been removed and a stand of herbaceous vegetation established, fire might be used to prevent reinvasion. The prospects are only moderately good at best, however, because rainfall where creosotebush thrives does not often produce enough herbage to carry a fire.

Cactus

Various cacti species are a nuisance on substantial areas of semidesert range. Most widespread in southern Arizona are the cholla or tree cactus forms that predominate at the lower elevations and lower rainfall portions of the region. Cholla is a problem primarily because it occupies space and interferes with handling of cattle. It does not appear to compete seriously with perennial grasses. Due to the spines, however, grasses that grow under cholla are not available to cattle. Thus cacti interfere more with the use of grasses than with their growth. Cholla stands in southern Arizona usually are not permanent (fig. 20). Stands tend to increase over a period of years, then die from natural causes. The cycle from invasion to die-off may run 40 to 50 years.

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[6] *Notes from "Impact of grazing on the ecology of the Southwest," by Dr. W. A. Dick-Peddie, at 21st Annu. Meet., Am. Soc. Range Manage., Albuquerque, N.M., Feb. 1968.*

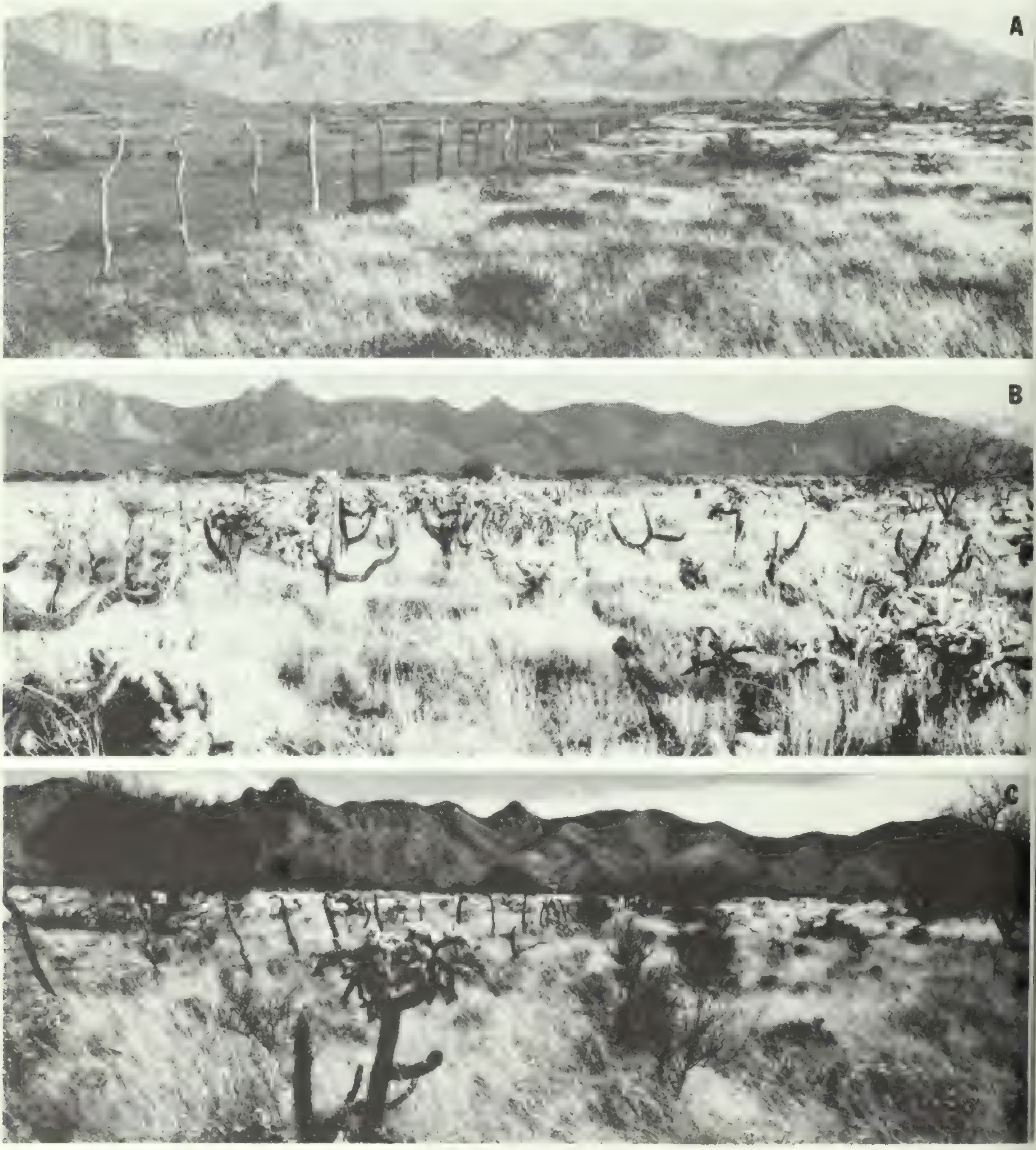

Figure 20.—Changes in jumping cholla:
A, in 1905 cholla was just beginning to invade;
B, by 1941 a dense mature stand had developed and had started to decline;
C, very few live cholla remained in 1962.

The chollas are fairly resistant to light applications of such herbicides as 2-4-5,T and 2-4,D. Each plant must be completely wetted. Chollas can easily be knocked down with a cable or chain. This method is quite effective in senescent stands. The number of rooted chollas per acre may jump manyfold after cabling due to the rooting of joints on the ground, but most of these new plants die in about 3 years (Martin and Tschirley 1969).

Fires in June have killed about 50 percent of the cholla on the Santa Rita. Surviving plants usually were large individuals that were only partially burned. Periodic burning should be an effective tool for preventing cholla invasion.

Pricklypear is a problem mainly where rainfall is somewhat higher than on areas occupied by cholla. Pricklypear apparently is less conspicuously cyclic than the cholla. It is equally hard to control with herbicides and about equally susceptible to fire.

Burroweed

Burroweed is of concern primarily in southern Arizona and southwestern New Mexico. Although it is toxic, native cattle are rarely poisoned. It germinates in the fall or winter on cool-season moisture. It competes less severely with the grasses than does mesquite because (1) it grows primarily in the spring whereas grasses grow mainly in the summer, and (2) because its taproot system draws less heavily from soil moisture near the surface than is the case for perennial grasses. Burroweed stands tend to build up if cool-season moisture is above average, and decline when cool-season moisture is severely below average.

Grubbing, mechanical treatments, and prescribed fire can all be used to control burroweed (Tschirley and Martin 1961). Grubbing generally is too expensive. Mowing in June or July is effective, but only on relatively level, rock-free terrain. Results with herbicides such as 2-4,D have been erratic. Burning in June with 500 pounds or more of herbage per acre may kill up to 90 percent of the burroweed. Burning simply to control burroweed may not be feasible, however, not only because burroweed control does not greatly increase production of perennial grasses, but because many of the better perennial grasses are severely damaged by fires of the intensity needed to kill burroweed. Also, burroweed can quickly reoccupy the burned area if cool-season precipitation is high.

The fact that burroweed stands usually decline of their own accord after a few years also reduces urgency for burroweed control. Wooton (1916) reported an invasion of burroweed in 1903 near the southwest corner of the Santa Rita Experimental Range. By 1917 a considerable part of the burroweed was dead. Wooton attributed death of burroweed to crowding by grass. Whatever the cause, burroweed stands apparently were changing from year to year during the first two decades after the range was established. Two additional burroweed invasions have been recorded since. One reached its zenith around 1935, the other in 1968.

Another reason for caution about burroweed control is that most of the perennial grass plants on a rundown range are intermingled with burroweed or other shrubs. Removing the burroweed from such ranges would expose these remnant perennial grasses to increased grazing. Therefore, burroweed control on ranges where grazing is excessive may only accelerate the decline of perennial grasses.

Snakeweed

Snakeweed, also a cool-season germinator, is more widespread than burroweed. Like burroweed, it is toxic although usually not fatal to cattle. More commonly, consumption of snakeweed by cattle results in abortion. Snakeweed can be controlled with ester formulations of 2-4,D. Aerial or ground sprays of 1 to 1½ pounds per acre (acid equivalent) in 10 gallons of water or oil-water emulsion are recommended. Spraying 2 years in succession is often necessary to control seedlings that emerge after the initial spraying. Time of spraying is critical. It should be done early in the spring when new growth is 3 to 5 inches and while there is enough moisture in the soil to keep plants growing 2 or 3 more weeks.

Snakeweed differs from burroweed in that it has a fibrous root system that occupies about the same soil levels as the roots of perennial grasses. Thus snakeweed may compete more directly with grasses than burroweed does.

Summary

The current situation with respect to shrub control is that, except for mesquite, control of noxious shrubs on semidesert range is not universally desirable. Some species such as burroweed and snakeweed increase and decrease in response to precipitation, and compete only moderately with perennial grasses. Cholla too competes only moderately with perennial grasses, but is objectionable because it interferes with the handling of cattle. Creosotebush competes seriously with herbaceous plants, and like mesquite seems to move in permanently, but economical methods for converting creosotebush stands to grass have not been developed.

Mesquites are the most consistently objectionable invaders of semidesert range. Mesquite control is recommended wherever perennial grass production is a major objective and benefits justify the cost.

Benefits may be in terms of increased forage production, or as insurance against a future decline in production as the density of mesquite increases and trees grow larger. Several control methods are available. The method used should be suitable for the kind of mesquite, for the site, and for the short- and long-range ranch management objectives. If beef is the only salable ranch product, complete clearing may be a reasonable objective. On the other hand, if opportunities to develop income from hunting privileges or other recreational enterprises are good, it may be desirable and profitable to leave patches of mesquite for wildlife food and cover.

More effective and more economical mesquite control methods are urgently needed. With current concern about side effects of herbicides, as well as about the desirability of tampering with range vegetation at all, more comprehensive ecological approaches are in order. The impacts of herbicides must be determined for nontarget species, and the impacts of resulting vegetation changes on bird and mammal populations should be a matter of record. Research on direct control methods should include combinations of treatments such as aerial spraying or cabling followed by burning or individual tree spraying, or cabling followed by aerial spraying.

Research on control methods for shrubs other than mesquite is of moderate priority—less important than grazing management.

Prescribed burning cannot be generally recommended on the basis of current knowledge. Fires that kill shrubs usually kill grasses too, and fires that spare the grasses may also spare the shrubs. Burning usually favors annual grasses and pioneer perennials at the expense of the better, longer-lived perennials. Still, periodic burning, combined with improved grazing systems, may effectively control semidesert shrubs. Research to learn how fire may be used acceptably and to good advantage should have high priority.

Emphasis in fire research should be on: (1) determining the responses of major grasses and shrubs to periodic burning, (2) fitting prescribed burning into schedules of grazing and rest, and (3) defining acceptable conditions for controlled burning.

Rodent and Rabbit Control

Rodents and rabbits use vegetation that would otherwise be available for livestock. Rodents and rabbits can be more detrimental to range plants than cattle because they graze much closer and may even dig up the plants during dry periods. Because populations of jack rabbits and kangaroo rats tend to be highest on ranges in poor condition, their impact becomes more severe as productivity declines. Certain species (the Merriam kangaroo rat, for example) help establish shrubs by burying seeds in shallow surface caches at the optimum depth for germination.

Direct methods of controlling rabbits and rodents by poisoning, trapping, shooting, rabbit drives, etc. usually provide only temporary relief and are rarely worth the cost. Prairie dogs have been eliminated from most of original range, it is true, but most other small mammals have survived man's most determined efforts to exterminate them. Vegetation management appears to offer a better approach to animal control. Improving the condition of a range from poor to good often eliminates the most evident rodent problems, but rodent control may be needed initially to start the upward trend. The availability of preferred food and cover as well as the balance between prey and predator species may be affected by the amount and kind of vegetation. And, while the causes and effects are not always clear, ranges in good to excellent condition rarely have serious rodent problems.

Fertilizer Applications

Fertilizers have been applied to rangelands to increase forage production, to lengthen the green forage period, to improve the chances for successfu establishment of seedlings, and have been suggested as a means of attracting cattle to little-used parts o the range. Fertilizers sometimes increase herbage production greatly, especially in seasons of above average rainfall. These increases, though dramatic may be of little practical use because ranges that are properly stocked always produce a surplus of forage in years of high rainfall. The extra forage produced by applying fertilizer in a wet year has little value fo the rancher if he does not have enough animals to use it. Fertilizer applications would be much mor helpful if they could be used to increase production in years of forage scarcity.

Fertilizers may have a place in the improvement o livestock distribution and in utilizing relativel unpalatable species. Applications of fertilizer ofte result in closer utilization of the fertilized plots. I many cases the fertilized plots are grazed evenly wit no apparent selectivity among species. This suggest that fertilizers can be used to enhance the palatabi ity of forage in areas that cattle often pass up. Th economics of such applications have not been invest gated.

Fertilizer may raise average levels of forage an livestock production above those that can be reache simply by improved grazing management, seeding and shrub control. In the northern plains, fo example, Rogler and Lorenz (1957) found that applying 90 pounds of nitrogen per acre for 2 year improved range condition more than did 6 years o rest.

In the Southwest, common observation indicates that plants growing under mesquite trees where soil fertility is higher withstand repeated grazing much better than grasses growing between shrubs on impoverished portions of the soil. These observations suggest that appropriate fertilizer applications may help perennial grasses survive and recover from drought. Much additional research is needed to establish appropriate levels of fertilization and to determine relative cost-benefit ratios.

Present knowledge is too limited to support general recommendations for range fertilization. Research has been limited mainly to empirical tests of the effects of fertilizers on herbage production immediately following application. A comprehensive program of basic research is needed. Areas that deserve immediate attention include: (1) effects of moderate to light applications of nitrogen or other nutrients on the species composition of the herbaceous vegetation, (2) effects of light to moderate fertilizer applications on herbage yield during moderate to severe drought, (3) effects of fertilizers on ability of grasses to withstand drought, (4) effects of fertilizers on ability of grasses to compete with seedlings of mesquite and other shrubs, (5) possibility of increasing herbage production in years of average or above-average rainfall to the point that native hay may be harvested for use in drought, (6) possibility of using fertilizers to raise the average level of production above the maximum attainable by management alone, and (7) possibility of using fertilizers to extend the green forage period.

Water Spreading

Opportunities to divert flood water from drainages to adjacent land exist on many ranges. On the average ranch such efforts should be confined to relatively small watercourses where water can be diverted without excessive expense, and where the risk of doing more harm than good is not great.

In a review of water spreading reports, Miller et al. (1969) concluded that water spreading did not do much good on thin or shallow soils. They found that yields greater than 1,000 pounds were obtained from soils capable of retaining between 14 and 40 centimeters of water, and recommended that floodwater spreaders should be restricted to soil deep enough to store at least 12 centimeters (4.7 inches) of water.

Increasing Usability of the Range

Water Development

Permanent natural waters on semidesert range are so few and so widely scattered that only a very small percentage of the area could be properly grazed by livestock from these natural waters alone. During the early days of livestock production on these ranges, vast areas could be grazed only intermittently. At times, lack of water saved these ranges from severe overgrazing, because livestock died or were removed during drought.

Ranchers and range investigators alike gave early attention to the development of livestock water. Barnes (1914) described the need for water on the range, methods for developing natural watering places, and possibilities for developing artificial watering places. The general principles of range water development are well established (Talbot 1926, Hamilton and Jepson 1940).

Talbot (1926) stated that permanent waters should not be farther apart than from 4 to 5 miles in flat or undulating country (14 to 24 sections per watering place); 3 miles in rolling country (6 to 12 sections per watering place); and from 1 to 2 miles on rough ranges (from 1 to 4 sections per watering place). Water development on most ranges in the Southwest probably meets these minimum standards of spacing and frequency. Many ranges of moderate to high productivity have more water places, while some of those of very low carrying capacity do not yet meet Talbot's standards because of the cost.

More recent writings deal largely with refinements of the basic techniques, and include such developments as deep-pit charcos, sand tanks, temporary ponds, and methods of reducing losses due to seepage and evaporation. Additional developments include (1) paved runoff areas with closed storage (trick tanks), and (2) horizontal wells (a method of developing weak springs or seeps).

Water development of any kind is expensive. Culley (1938b) stated that careful planning is required to insure that water is placed where it will yield the greatest return. He cited an example in which, by careful placement, a particular water source was made to serve 350 head of cattle rather than 120, and the investment per cow thereby reduced from $13 to $5. The cost of water development, when added to other investment costs, must not raise the investment load per cow above what can be economically justified.

Water development still is not adequate on many semidesert ranges. In some cases the water problem has been aggravated because springs or seeps now produce less water than they once did, or have ceased to flow altogether. Watersheds have become covered with shrubby vegetation that consumes so much water that none is left for underground flow, or, alteration of the soil surface through deterioration of the grass cover has reduced infiltration and percolation. In some areas it may be cheaper to restore the flow of streams or springs through shrub control than to drill wells to replace the original source.

Where underground water exists at reasonable depths, deep wells are the most reliable source of livestock water. Pumps powered by windmills with gasoline engines for standby power provide the permanent water on most ranches. Shallow wells are also common and useful, even though some of these do fail in periods of protracted drought. Storage tanks are necessary at most wells because either the well or the pump will not furnish more than a few gallons per minute. Where wells are very weak, covered storage is advisable to cut down evaporation.

Surface ponds are common on the semidesert ranges. Ponds range in size from very small developments which hold water for only a few weeks to large, deep structures that may hold water permanently. Ares (1936b) found that small inexpensive ponds enabled cattle to make better use of tobosa grass during the summer growing season, thereby reserving more of the black grama for the dormant season. These temporary ponds also decreased the grazing pressure near permanent waters. Hamilton and Jepson (1940) reported that ponds in the semidesert range area should be from 10 to 14 feet deep to provide reliable water yearlong. Most stock ponds are not nearly that deep, and provide water for perhaps half the year. Use of clay products or salts such as sodium carbonate to reduce seepage can reduce the necessary pond depth. If ponds are to be long lived, they must be properly constructed and placed so that they are not subject either to being washed out or filled with sediment during high flows. Areas above ponds should be fenced to allow vegetation to develop and trap sediment, thereby lengthening the useful life of the ponds. Water used by the vegetation in the silt trap is not enough to offset the value of the protection it gives.

Evaporation losses from ponds have always been a serious concern. In the Tucson area, for example, it has been estimated that a square foot of water will evaporate 50 gallons of water per year.

Three approaches to evaporation control are: (1) the use of hexadecanol, which has been only moderately successful because of the difficulty of maintaining a film of material on the water (Cooley 1975), (2) the use of styrofoam rafts floated on the water (Cluff 1972), and (3) a layer of wax for steel or concrete tanks (Cooley and Myers 1973). None of these are entirely satisfactory. Hexadecanol films are swept off by strong winds, styrofoam rafts break up eventually and must be replaced, and sufficient quantities of wax are not always easy to get.

A growing problem with ponds on some ranges is that, as management and the vegetation cover improve, once-reliable stock ponds rarely fill because the watershed has become more like a sponge than a tin roof. As the condition of the range improves, forage becomes more abundant but surface water less so. Faced with this situation, the rancher must make other arrangements for water; usually these involve tapping ground-water sources. Three developments within the last couple of decades offer some relief. These are: plastic pipe, trick tanks, and horizontal drilling.

If permanent water is available, plastic pipe can be used to distribute water from a central location at a relatively low cost. Flexible plastic pipe is not satisfactory in some areas, because gophers or other rodents gnaw through the pipe. In other areas the pipe must be carefully laid and covered to keep rocks from cutting the line. If flexible plastic pipe is not suitable, rigid plastic tubing is available at substantially lower cost than steel pipe.

Paved runoff areas with covered storage (trick tanks) also may be used to provide water for livestock. On some ranges the natural runoff from a paved road can be directed into storage; on others the runoff surface must be developed. A number of waterproof materials for covering the soil surface have been tried. These include butyl rubber, which is durable but quite expensive; polyethylene film, which is cheap but not very durable; concrete or asphalt which are both quite durable but expensive; and treating the soil with salt or water-repellent chemicals. In all cases a relatively small collecting area is made quite impervious to water. The most expensive part of such projects usually is the development o enough storage to last through dry periods.

Horizontal well drilling is economical for specia situations. Basically it is an improved method fo developing seeps or weak springs in hilly or mountainous terrain. A horizontal hole about 2 inches in diameter is drilled into the side of the hill at the chosen site. A pipe perforated in the water-bearing area remains in the hole to collect and carry water to the surface. Since water flows out of the well b gravity, no pump is required. To avoid wasting water, however, it is advisable to limit the flow to actual use with a float valve directly on the well Unrestricted flow might soon drain the well dry. O 58 wells drilled on the San Carlos Indian Reservation in Arizona, only seven were reported to be failures i the fall of 1969. The average well was 97 feet dee (or long) and the average cost per producing well wa $411.

The secret of successful horizontal well development is to drill in the right place. A competen geologist can improve the probability of success However, the better horizontal well contractors ar reasonably good amateur water geologists themselves.

encing

Range fences no longer serve only to keep the ancher's cattle at home; they also meet specific ivestock and range management needs. Separate astures for replacement heifers or for bulls during he nonbreeding season are common. For purebred erds, pastures are designed to carry the number of ows (usually 50 or fewer) that can be serviced by one ull. Or, the size of the pasture may be limited by he amount of stock water. Aside from such limitaions as these, the number of cattle in a pasture robably is not critical, although calf crops reportedy are higher in units of about 50 cows than in arger units.

A major objective of crossfencing for subdividing range unit is to provide opportunities for range nprovement by such methods as seeding, shrub ontrol, and systems of alternate grazing and rest.

Economics dictates that ranges be subdivided no ore than necessary for good range and animal anagement. Conventional fencing with four barbed ires and steel posts about 30 feet apart may cost round $1,500 per mile on level soft ground; much ore on rough, rocky, or bushy terrain. "Suspension" nces constructed of 13½-gage high-tensile-strength ire with posts 100 feet apart and stays between are ss expensive than standard fences, and may well be fective so long as there is no great temptation for ttle to cross from one side to the other. Cattle with strong inclination to cross the fence can learn to lift e wire midway between posts, however, and crawl nder.

New fences should be located only after careful nsideration of such factors as topography, vegetaon type, natural trails, and water that affect cattle ovements and access to all parts of the resulting nge units.

alting

Proper distribution of grazing is essential for ficient use of grass-shrub ranges. Salt or suppleent can sometimes be used to draw cattle to areas here forage is abundant but not fully used.

For many years salt was placed at water on southestern ranges in the belief that salt made cattle irsty, and that placing salt away from water would use cattle to go directly from salt to water. A umber of observations, however, have shown that ttle ordinarily lick salt after drinking rather than fore, and that when salt is placed away from water ttle usually leave the salt station to graze rather an go directly to water (Ares 1936a, Culley 1938a, mo and Klemmedson 1970).

Salt placed away from water, where forage is abundant, usually improves the distribution of grazing. If there is little or no salt in the vegetation and no natural salt licks, salt can be a relatively satisfactory distribution tool.

If cattle do not seek out a salt block that is placed away from water, or return to it once they know where it is, some other means of improving distribution will have to be used. This may happen on ranges with natural salt licks or with salt in the forage, as in saltbush stands.

Ares (1953) found that feeding meal-salt mixtures away from water greatly improved the distribution of grazing use by steers from November through June in southern New Mexico. Consumption of meal-salt declined when green herbage became available in the spring, a phenomenon confirmed in a more recent study in Arizona (Martin and Ward 1973). No evidence of salt toxicity was reported in either study. Ares also observed that cattle did not travel directly from the meal-salt station to water but continued to graze after feeding. These results show that meal-salt mixture can be used to improve the distribution of grazing use as well as to compensate for nutritional deficiencies in the native forage.

Riding

Riding to increase usability of the range may or may not do much good. The keys to successful riding are common sense, persistence, and culling. Pushing cattle to where the grass looks good but where there is no water is usually futile because the cattle will be found at their old location 24 hours later. The common sense rule, then, is to move cattle to grass only if there is water. Cattle may have to be met daily and pushed back to the new location for a week or more before they will accept the move. Animals that refuse to stay where they are put should be removed from the herd. Chronic cases of poor distribution may require additional water development, crossfencing, or a change in the grazing system, as well as persistent riding, to break up the old use pattern.

Trail Construction

Most semidesert ranges are relatively flat and easily traversed by cattle, but include some partial barriers to cattle movements. Trails built across steep-sided gullies or arroyos make it easier for cattle to get to where the forage is. Exit trails off roads that run across the slope on steep terrain may also be worthwhile. Some ranchers also report good results from crude trails on steep hillsides. Such crude trails can be built with one pass of a moldboard plow. Trails should be so located and engineered that they do not develop into gullies.

Summary

Practices for increasing the usability of ranges grazed yearlong are almost standard and generally accepted. However, the usual recommendations for number and spacing of waters, size of range units, placement of salt, and the need for riding or for trail construction may have to be revised as ranges are converted from yearlong grazing to systems that include alternate periods of grazing and rest.

Except for critical distribution problems, the priority for continued research in trail construction is relatively low.

Livestock Management

Most ranchers are better versed in animal husbandry than in the ecology and physiology of range plants. This is natural because their income is derived from the sale of the animals rather than from the sale of unconverted forage. Acceptable solutions to most of the critical problems of range livestock husbandry have been developed. Nevertheless, there is room for improvement.

Every effort should be made to keep cattle gentle. Cattle that see a rider only at roundup time tend to become wild. Frequent riding, gentle methods, and modern conveniences for handling livestock greatly reduce losses and injuries. Holding traps, corrals, squeeze and separating chutes, and branding tables greatly reduce labor. Gentle cattle are much easier and cheaper to handle than are wild cattle.

Animal Nutrition

The nutritive quality of most semidesert range forage plants is adequate during the active growing period, but the common perennial grasses are usually deficient in protein during midwinter. Phosphorus and vitamin A are also inadequate at times. However, cattle are able to select the most nutritious forage from that available. On ranges where there is a variety of shrubs as well as grasses, cattle usually select a diet adequate in protein in all but the coldest part of the year (Cable and Shumway 1966). On grass ranges, however, cattle diets may drop below minimum levels of protein and phosphorus shortly after the first hard freeze, and continue deficient until growth resumes in the spring (Stanley and Hodgson 1933). In some situations, supplemental vitamin A may be needed in midwinter. On grass ranges, therefore, range cows probably should receive essential supplements from early winter until spring growth begins. On grass-shrub ranges the feeding period may be shorter or in some cases may be eliminated altogether. Range cows can be allowed to lose some weight (up to about 100 pounds) during winter without damage to health or serious decline in productivity. Feeding enough supplement to maintain body weight of cows during the winter is wasteful.

Animal Breeding

Hereford cattle predominate in the semidesert region. However, the February 1975 issue of New Mexico Stockman contains feature articles and/or advertisements for Angus, Simmental, Limousin, Charolais, Chianina, Scotch Highland, Brangus, Santa Gertrudis, and Beefalo as well as for Herefords. Crossbreds such as Barzona, Brangus, and Santa Gertrudis are gaining popularity on some desert ranges because the animals are better able to stand the heat and can travel greater distances between feed and water than can the common English breeds. Crossbreds are also favored on some ranges because they produce bigger, heavier calves. To some extent, however, the advantage of larger calves is offset by the fact that some crossbred herds produce lower calf crops.

Herbel and Nelson (1966) report that Santa Gertrudis cows consume more of the coarse grasses than the Hereford, but that the Herefords eat more Russianthistle and yucca. They also report that the Herefords spend more time grazing, less time walking, and travel less distance than the Santa Gertrudis. Generally speaking, the differences were not great enough to justify recommending one breed above the other. There is no consensus as to which other breed or crossbred will eventually exceed the Hereford in popularity.

The rancher must meet market demands. Sometimes larger calves are an advantage. At other times the greater weight is a disadvantage because feeders want smaller animals. Generally speaking, the packers prefer a heavier carcass because the cost of processing depends more on the number of animals than on the weight handled, and because the larger-framed animal reaches an acceptable weight carrying less waste fat. If the apparent trend toward heavier animals continues, the heavier cattle breeds will continue to replace Herefords.

Another concern where grazing systems result in changes in pasture and herd size is the impact of such changes on calf crops. The effects of larger herd sizes on calf crops under complex grazing systems are uncertain. Bull-cow ratios in common use on semidesert range have evolved mainly out of experience under yearlong grazing. These ratios may not be optimum for more complex grazing systems.

Herd Composition

Cow-calf operations have predominated on semidesert range in the past, but recent and prospective economic developments suggest that cow-yearling operations may be more profitable in the future. Since semidesert forage produces rapid animal weight gains only during the summer growing season, most semidesert ranches have been cow-calf operations for good reason. Calves are born in the early spring and sold in the late fall as weaner calves. This schedule fits in well with the timing of forage growth. Calves born in January, February, or late December are large enough to take the increased milk flow during the summer rainy season, and usually are about as heavy in the late fall as they would be 6 to 8 months later after wintering on the range. Yearlings held over for a full year mark time for 6 to 8 months (November through April or June) and make all of their gain for the year during the remaining 4 to 6 months. Special situations that are better suited to yearlings or steers than to cows and calves include rough or rocky range that is better used by lighter, more active animals, and remote or brushy ranges where losses of young calves to predators are excessive.

For cow-calf operations on ranges grazed yearlong, Paulsen and Ares (1962) suggest that the breeding herds should be kept well below the average capacity for the range, and that extra forage in good years should be utilized by carrying over extra yearlings. In years of low production, the normal complement of yearlings would be sold and only the breeding herd would be kept. A serious shortcoming of flexible stocking in cow-calf operations is that each year's forage crop is not known until the growing season is over. If extra animals are put on the range in the fall following a good summer forage crop, they should be sold in May or June before the new growing season starts. In most years this is not profitable because weaner calves gain little in weight or value during the dormant season. Also, the range will be overstocked during the growing season unless forage growth is above average.

In a more recent evaluation of flexible stocking on a yearlong cow-calf operation, Martin (1975) found that net sales were highest when the breeding herd was maximized, and that it did not pay to stock above the average carrying capacity following summers of high production. The breeding herd was maximized by breeding cows to calve first at age 2 and by keeping a minimum number of replacement heifers. The number of replacement heifers can be kept small if cows are normally culled for age at age 8. If this is done, a cow can be held over an extra year or so if a replacement heifer dies, does not turn out well, or fails to breed back. If forage production is low, stocking can be reduced to 91 animal units by selling the replacement heifers. More severe cuts must come from the breeding herd. A 100-animal-unit cow-calf herd would consist of 87 cows and 15 replacement weaner heifers (0.6 AU each) and 4 bulls.

Cow-yearling operations offer greater flexibility for reducing stocking after dry summers but fewer animals are marketed than with cow-calf operations. Assuming 90 percent calf crops, and no death loss, with cows calving first at age 2 and culled normally at age 8, a 100-animal-unit cow-yearling herd would consist of 63 cows, 3 bulls, 11 replacement heifers, and 46 carryover yearlings. If necessary, the 46 carryover yearlings can be sold as calves, thereby reducing stocking to 73 animal units without selling breeding cows or replacement heifers. However, selling carryover yearlings as calves increases income this year but reduces it a year later.

The question is, which is the more profitable, a cow-calf herd or a cow-yearling herd? Much depends on the price per pound for calves and yearlings and on their average weights. Cattle prices through 1973 generally favored the cow-calf operator. Cattle feeders paid more per pound for calves than for yearlings because feed grains were so low in price that the feeder could add a pound of gain in the feedlot cheaper than he could buy it on the animal. High feed prices in 1974 together with lower beef prices reversed the situation.

The future of cattle prices is uncertain. It appears that the days of abundant cheap feed grains may be over. Also, as arable land shifts from feed crops to food crops, a higher percentage of the nation's beef will have to be produced from range forage and roughage. In any event, the relative advantages of cow-calf and cow-yearling operations can be estimated if the prices and weights of calves and yearlings are known. For example, if calves and yearlings sell for the same price per pound, the yearlings must weigh about 550 pounds to bring in as much as 400-pound calves (table 2). On the other hand, if the yearlings weigh 650 or more pounds they can sell for less per pound than calves and still produce more income. Computations in table 2

Table 5.--Break-even price for yearlings, compared to that for 400-pound calves sold in the fall

Weight of yearling (pounds)	Comparative price per pound for calves sold in fall				
	$0.25	$0.35	$0.45	$0.55	$0.65
	Break-even price for yearlings				
350	$0.40	$0.56	$0.71	$0.87	$1.03
450	.31	.43	.56	.68	.80
550	.25	.35	.45	.56	.66
650	.21	.30	.38	.47	.56
750	.18	.26	.33	.41	.48
850	.16	.23	.29	.36	.42
950	.15	.20	.26	.32	.38

assume yearly sale for cow-calf operations of 63 calves and 15 cull cows, plus 6 percent interest for 1 year on the sale value of the calf. For cow-yearling operations, the yearly sale would consist of 46 long yearlings and 11 cows.

Shifting from cow-calf to cow-yearling production reduces the number of animals marketed by about 27 percent. This could relieve the apparent oversupply of beef, reduce cattle inventories, and greatly reduce the amount of grain fed to beef cattle not only because fewer animals would be fed but because animals would enter the feed lot 200 to 400 pounds heavier.

Flexible or Constant Stocking

A major problem in making efficient use of forage is that production varies unpredictably from one year to the next. Grass yields may be as low as 60 or as high as 160 percent of the average. How can a rancher maintain a stable business in the face of such variations in forage yield? Is it better to adjust animal numbers to the forage crop each year, or should the range be stocked at a conservative but relatively constant rate?

One appeal of flexible stocking is that it allows more complete use of the forage in years of high production. This is commonly believed to increase ranch income, thereby offsetting low income and high expense in years of low production. Martin (1975), however, found that net sales per 100 animal units obtained by increasing stocking to 120, 130, or 140 percent of average in the best years were only $100 to $200 greater than for constant stocking at 90 percent of the level required for proper stocking in an average year. In practice, this small monetary advantage would probably be offset by the apparen disadvantages of the flexible system. These include the sheer difficulty of estimating forage crops and adjusting animals accordingly, possible seriou damage to the range in years of low forage production when stocking is high due to high production the year before, the administrative costs of buying extra animals to stock the range in good years, the possibility of introducing parasites or disease with cattle from off the range, and the natural reluctance to cull as heavily as necessary for the good of the range in drought years. Constant stocking at 90 percent of average proper stocking appears to offe stability of operation, relatively high income, and moderate to low risk of damage to the range o financial crisis during drought. Even better for th range would be stocking at not to exceed 90 percen of average proper stocking, but with some reduction during prolonged severe drought.

Summary

Knowledge about managing livestock is generall adequate and readily available to the ranch operato Furthermore, the direct economic importance o decisions in this field are so apparent to the rancher that he keeps abreast of developments on his own Certainly the final answers to all questions abou managing livestock are not yet in, but the priorit of such questions for research by the Forest Service is quite low.

Correlating Grazing With Other Uses

Forage is a major product on semidesert range and is marketed primarily through livestock. Other products of the range include water, timber, wildlife and recreation.

Water and Wood

Semidesert ranges produce limited quantities o wood for fuel or for charcoal and fenceposts. Wate yields from semidesert ranges likewise is relativel low, but the quality of water produced and the rat of runoff are greatly affected by grazing management. Well-managed ranges with a good cover grasses yield water of higher quality and lower peak flood flows than do ranges with poorly dispersed cover. Good range management therefore is goo watershed management. Likewise, removal of mes quite from semidesert ranges almost always improve forage production, ground cover, and water quality Tree growth and forage growth apparently ar competitive.

Surface water yield from ranges in good condition ay be lower than on ranges in poor condition, but wer yield of water is offset to a degree by the higher uality. The yield of springs usually improves if rush is removed and better grass cover is estab-shed.

ildlife

Most semidesert ranges support some wildlife. esert mule deer, javelina, antelope, desert bighorn eep, quail, doves, and rabbits are all hunted in ason. Numerous nongame birds and animals, ative to these ranges, are also becoming increasingly rominent in the public eye. Many semidesert ranges at once were almost pure grasslands now support oderate to dense stands of mesquite and other rubs. The increased shrub cover has improved the abitat for deer and other wildlife; at the same time, rage production for livestock has decreased.

Near the eastern edge of the semidesert area in the dwards Plateau region of Texas, ranchers now tain a substantial part of their income from the le of hunting privileges. Where the demands of ban sportsmen are great enough, a rancher may ofitably manage his range to produce a mixture of ildlife and game if the vegetation on his range and e existing legal framework permit him to do so. In anning such a venture the rancher must consider any factors, including the relative effectiveness of asses and shrubs for erosion control.

ecreation

Rangelands furnish an essential part of the creational opportunities of the West. Desert out-gs during the spring flower season; off-road vehicle cursions; dude ranches, based on the perpetuation the spirit of the Old West on a deluxe scale; con-ntrations of use by tourists in especially attractive nyons; and use in varying degree of an untold umber of resorts and campgrounds are now com-on and will increase. The use of the range country r recreation seldom needs to interfere seriously with nge livestock production.

Recreational use is beginning to become an portant source of income in the range country. any ranchers who formerly depended entirely on estock for their income now supplement this with turns from dude ranching. On some ranches the creational venture now dominates, and the live-stock is little more than a feature to attract and tertain the guests. Recreational use promises to be major factor in the social and economic life of the untry.

Little is known of the relative compatibility of range livestock production with wildlife or recreation. The priority for research in this area is extremely high. Public land administrators need sound information on which to base decisions involving land-use conflicts. Land-use decisions are being questioned with increasing frequency and severity as more and more interest groups assert their views as to how semidesert ranges should be used.

Administrators of public rangelands must also be concerned with who pays the costs of management, improvement, and administration. The rancher pays grazing fees, the hunter or fisherman buys a license, and recreationists pay for the use of certain facilities. Many who enjoy the out-of-doors, however, pay nothing directly for the maintenance or improvement of the wide-open spaces they enjoy. The question of who pays for what needs to be answered, especially in cases where recreation replaces grazing as the dominant use.

Research in this field must deal with the entire ecosystem. A multidisciplinary program is needed not only to evaluate the impact of range management and improvement practices on forage, water, and wildlife, but to evaluate the impact of such practices on recreational opportunities.

RESEARCH RECOMMENDATIONS

Much semidesert range is producing far below its potential. Poor-condition ranges yield such hazards as flash floods and duststorms. More effective vegetative cover can improve the economic plight of ranchers and reduce offsite damage as well.

Properly managed ranges yield essential animal products at low cost for fossil energy without creating the additional problems of odor control and manure disposal that are associated with closely confined livestock. Those ranges also provide wildlife habitat and a variety of recreational values. A few lines of research that are needed to enhance the value of semidesert ranges to society are:

- Classify and develop readily comprehensible indices and standards of productivity for major semidesert range sites.
- Evaluate the impacts of alternative land treatments, and combinations of treatments and uses on such sites.
- Evaluate alternatives to continuous yearling grazing.
- Develop standards of utilization for major range sites that are compatible with such grazing systems.
- Identify and evaluate the beneficial effects of grazing.

- Evaluate the possibilities of prescribed burning in combination with other shrub control methods as a tool for manipulating semidesert vegetation.
- Evaluate the impacts on wildlife, scenic beauty, and other recreational amenities of programs designed to increase production of grass and beef.
- Evaluate the potential demand for and utilization of semidesert range for recreation.

SUMMARY AND CONCLUSIONS

The vegetation of much semidesert range has changed greatly since domestic livestock were introduced about 100 years ago. Generally, the change has been characterized by a reduction in perennial grasses and an increase in such shrubs as mesquite, creosotebush, and cactus. Although the quality of management has improved greatly on most semidesert ranges within the last two or three decades, the majority of semidesert range is producing less forage than it is capable of.

For at least 20 years, cattle ranching in the semidesert has not been highly profitable except when cattle prices were high. Ranches sell for about four times their value for range livestock production. Speculation in land based on the current southwestern land boom, and purchase of ranches by wealthy individuals, have contributed to the current high price of rangeland. Production ranchers cannot compete with consumption ranchers in bidding for ranch property. Still, grazing will continue to be the major use of most semidesert range.

Grazing during winter apparently is not harmful to perennial grasses, but grazing either in spring or summer if too frequent or too heavy will reduce the vigor and density of perennial grasses. From a livestock production viewpoint, yearlong grazing is an acceptable system for semidesert ranges, and generally does not result in severe depletion of the range resource if utilization does not exceed an average of about 40 percent. The deficiency of yearlong grazing is that uneven distribution of use from place to place and among species cannot be avoided. The only systems of grazing that have proved superior to yearlong conservative grazing are those that provide relatively long rest periods (from 1/3 to 2/3 of the total elapsed time) with rest during the spring and summer growing periods.

Acceptable procedures for seeding have been developed for ranges with annual precipitation of 13 inches or more. The success of seeding on drier ranges is less certain, but can be enhanced greatly by pitting to increase infiltration of rainwater. New seedings must be protected from grazing for at least one growing season; protection for two seasons is recommended.

Mesquite control has proven beneficial througho almost all the semidesert area. Several mechanic and chemical control methods have been develope each is peculiarly suited to certain situation Progress on development of chemical contr methods has been slowed by concern over enviro mental impacts. The average rancher with mesquite-infested range can supply forage for ad tional cattle much more cheaply by controlli mesquite than by purchasing additional land. T value of controlling creosotebush, cactus, burrowee and snakeweed is much less clear.

The use of fire as a tool for manipulati vegetation on semidesert range deserves furth study. Fire is relatively effective against burrowe and cactus, but only moderately effective again creosotebush and mesquite. A problem with fires that the kinds of fire that are effective again shrubs severely damage perennial grasses. Still the is a possibility that periodic burning, coordinat with an appropriate system of grazing, can be used maintain a grasslike aspect once the initial stand shrubs has been controlled by some other method.

Experimental applications of nitrogen have grea increased herbage production of annual and pere nial grasses in years of average or better-tha average summer rainfall. The economics, howeve have not been determined. Also the possibilities using small amounts of fertilizer to speed up ran improvement and to improve distribution of use ha not been adequately investigated.

Techniques of water development, fencing, s placement, riding, trail construction, and so fo have been fairly well developed. Two relatively n developments in the field of water development a the horizontal well and the trick tank. These devi may assume more importance as the quality of ran management improves and surface ponds beco less effective.

Semidesert ranges provide a home for desert m deer, javelina, and a variety of small animals a birds. In some cases the decline in productivity semidesert range for livestock due to increases shrubs has resulted in an increase in wildlife. T socio-economic climate now is such that maxim livestock forage is no longer an acceptable goal all semidesert range. Instead, some pattern vegetation that provides food and cover for wild as well as livestock may be more acceptable.

Poorly managed semidesert range contribu negative offsite values including dust, silt, and pe flood flows. A dense, well-dispersed perennial gr stand probably offers the best protection to surface soil and minimizes these negative values.

Use of semidesert lands for hunting, hiking, ro hounding, birding, and related activities is incre

g. Off-road vehicle travel is another interest that oses a threat to the stability of semidesert soils. ecreation and livestock production need not neces- rily compete. Increasing range livestock production ay actually enhance recreation values by increasing e opportunities for recreationists to see range imals.

Urban people are taking an increased interest in hat happens on semidesert rangelands, particularly ose in public ownership. Much of the semidesert nge near major population centers will eventually into suburban housing or other nonrange uses. ore remote parts of the range will be visited by nters and recreationists, and will provide an pportunity for ranchers to develop a second source income.

Range livestock production produces a usable oduct for society with little expenditure of fossil el. Range livestock are also produced without the oblems of offensive odors and manure disposal oblems characteristic of feedlots. Thus, range estock production under good management prac- es has little or no adverse impact on the environ- ent.

New research on semidesert range should empha- ze: (1) classification, description, and evaluation of midesert range sites, (2) evaluation of promising azing systems, (3) evaluation of prescribed burning a tool for maintaining desirable vegetation tterns, (4) evaluation of the impacts of range anagement practices on wildlife, scenic beauty, and her recreational attributes, and (5) evaluation of e current and potential demand for recreational e of semidesert range.

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COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

Perennial Grasses

Common Name	Botanical Name
Alkali sacaton	*Sporobolus airoides* Torr.
Arizona cottontop	*Trichachne californica* (Benth.)
Black grama	*Bouteloua eriopoda* Torr.
Blue grama	*Bouteloua gracilis* (H.B.K.) Lag.
Blue panicum	*Panicum antidotale* Retz.
Boer lovegrass	*Eragrostis chloromelas* Steud.
Buffelgrass	*Pennesetum ciliare* (L.) Link.
Bush muhly	*Muhlenbergia porteri* Scribn.
Curly mesquite	*Hilaria belangeri* (Steud.) Nash
Green sprangletop	*Leptochloa dubia* (H.B.K.) Nees
Hairy grama	*Bouteloua hirsuta* Lag.
Johnsongrass	*Sorghum halepense* (L.) Pers.
Lehmann lovegrass	*Eragrostis lehmanniana* Nees
Mesa dropseed	*Sporobolus flexuosus* (Thurb.) Rydb.
Mixed gramas	*Bouteloua* spp.
Plains bristlegrass	*Setaria macrostachya* H.B.K.
Plains lovegrass	*Eragrostis intermedia* Hitchc.
Rothrock grama	*Bouteloua rothrockii* Vasey
Santa Rita threeawn	*Aristida glabrata* (Vasey) Hitchc.
Sacaton	*Sporobolus wrightii* Munro
Sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray
Sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.
Slender grama	*B. filiformis* (Fourn.) Griffiths
Sprucetop grama	*Bouteloua chondrosioides* (H.B.K.) Benth.
Tall threeawns	*Aristida hamulosa* Henr. and *A. ternipes* Cav.
Threeawns	*Aristida* sp.
Tobosa	*Hilaria mutica* (Buckl.) Benth.

Forbs

Common Name	Botanical Name
Filaree	*Erodium cicutarium* (L.) L'Her.
Leatherweed croton	*Croton corymbulosus* Engelm.
Russianthistle	*Salsola kali* L.
Spectacle-pod	*Dithyrea wislizenii* Engelm.
Woolly paperflower	*Psilostrophe tagetinae* (Nutt.) Greene

Trees and Shrubs

Common Name	Botanical Name
Acacias	*Acacia* sp.
Burroweed	*Aplopappus tenuisectus* (Greene) Blake
Catclaw acacia	*Acacia gregii* A. Gray
Cholla	*Opuntia* sp.
Creosotebush	*Larrea tridentata* (DC.) Coville
Fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.
Juniper	*Juniperus* spp.
Mesquite	*Prosopis* spp.
Pricklypear	*Opuntia engelmannii* Salm-Dyck
Snakeweed	*Gutierrezia* spp.
Soaptree yucca	*Yucca elata* Engelm.
Tarbush	*Flourensia cernua* DC
Wait-a-bit (catclaw mimosa)	*Mimosa biuncifera* Benth.
Whitethorn	*Acacia constricta* Benth.

Martin, S. Clark.
1975. Ecology and management of southwestern semidesert grass-shrub ranges: The status of our knowledge. USDA For. Serv. Res. Pap. RM-156, 39 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

The vegetation on much southwestern semidesert range has shifted from grassland to brush since livestock ranching began 100 years ago. Shrub control, reseeding, and improved grazing management have reversed the downward trend on some ranges but most ranges are producing below their potential. The role of ranges in meat production will become more important as increased population requires that arable lands be used mainly for food production.

Keywords: Semidesert range, grazing system, plant control, multiple use.

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Although this report discusses research involving pesticides, such research does not imply that the pesticide has been registered or recommended for the use studied. Registration is necessary before any pesticide can be recommended. If not handled or applied properly, pesticides can be injurious to humans, domestic animals, desirable plants, fish, and wildlife. Always **read** and **follow** the directions on the pesticide container.

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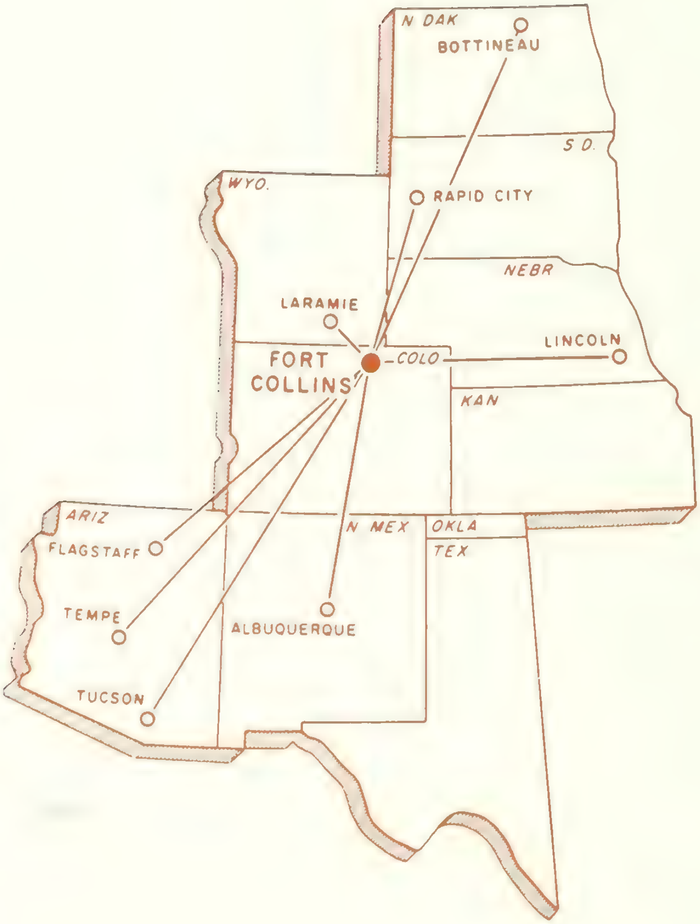
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Alpine Range Management In The Western United States — Principles, Practices, And Problems:

The Status of Our Knowledge

John F. Thilenius

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USDA Forest Service
Research Paper RM-157
November 1975

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Thilenius, John F.
1975. Alpine range management in the western United States—principles, practices, and problems: The status of our knowledge. USDA For. Serv. Res. Pap. RM-157, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

Keywords: Alpine ecosystem, alpine range management.

JSDA Forest Service
Research Paper RM-157

November 1975

ALPINE RANGE MANAGEMENT IN THE WESTERN UNITED STATES— PRINCIPLES, PRACTICES, AND PROBLEMS:

The Status of Our Knowledge

John F. Thilenius, Principal Plant Ecologist
Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University; esearch reported here was conducted at the Station's Research Work Unit at Laramie, in cooperation with he University of Wyoming.

Contents

Page

INTRODUCTION 1
THE ALPINE ZONE 1
  Definition 1
  Geographic Distribution 1
  Altitudinal Limits 2
  Macro Land Forms 2
  Micro Land Forms 3
  Soils 3
  Climate Regime 5
    Moisture 5
    Wind 7
    Radiation 8
    Temperature 8
  Floristics 9
  Animals 9
ALPINE ECOLOGY 10
  Adaptations of Plants to the Environment 10
  Growth and Development 10
  Biomass and Productivity 11
  Phytosociology 12
RANGE MANAGEMENT IN THE ALPINE ZONE 14
  Domestic Livestock Grazing 15
  Grazing Systems 15
  Range Readiness 17
  Quantity and Quality 17
  Preference and Utilization 18
  Range Condition and Trend 20
  Range Improvement 22
  Integration with Other Uses 23
    Watershed 23
    Wildlife 24
    Recreation 26
    Mining 27
SUMMARY AND CONCLUSIONS 28
LITERATURE CITED 29

ALPINE RANGE MANAGEMENT IN THE WESTERN UNITED STATES— PRINCIPLES, PRACTICES, AND PROBLEMS:
The Status of Our Knowledge

John F. Thilenius

INTRODUCTION

Because of the steep, rugged topography, high erosion potential of the soils, and the short growing season, alpine ranges present special management problems. Basic knowledge of their ecology is therefore prerequisite for managers to properly allocate the various resources of the alpine zone. The first portion of this Paper characterizes the zone; the second reviews the present status of our knowledge of the ecology of the alpine area; followed by the management of the ecosystem, with emphasis on the use of the forage resource.

THE ALPINE ZONE

Definition

Alpine ecosystems occupy those mountain areas above timberline that are characterized by hort, cool growing seasons and long, cold winters. The vegetation is characteristically dominated by ow-growing (ca. 20 cm or less), perennial, herbaeous, and shrubby vascular plants; extensive mats of cryptogams (mosses, lichens, etc.); and the lmost complete absence of trees (fig. 1).

Geographic Distribution

In western North America, alpine ecosystems xtend from the Arctic southward along the Rocky Mountains and Cascade-Sierra Nevadas. In the con-

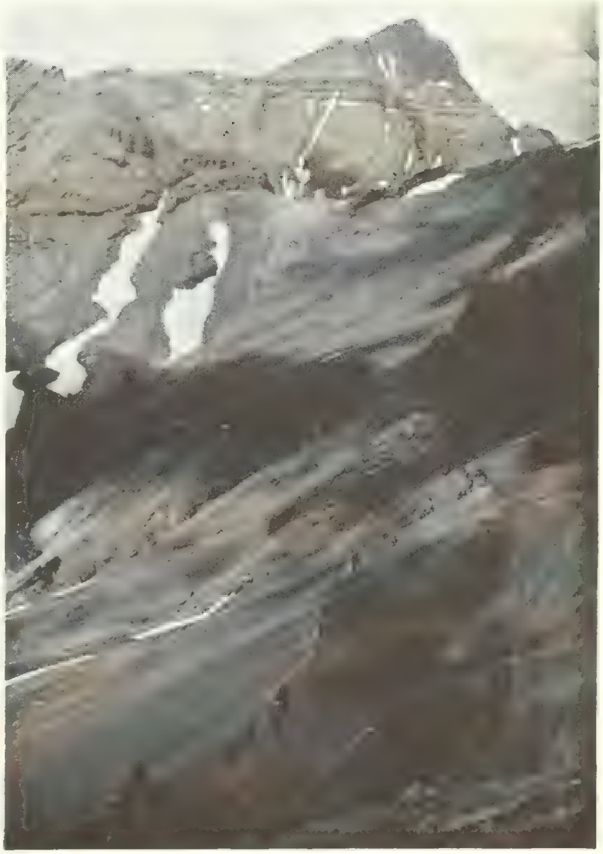

Figure 1.—Alpine rangeland in the Absaroka Mountains of northwestern Wyoming.

terminous United States, the Rocky Mountain segment is found on the highest portions of the mountain ranges between the Great Plains and the Great Basin, from Montana southward to the Sangre de Cristo Mountains of New Mexico. Outliers occur on San Francisco Peak in Arizona (Little 1941), and on the summits of the higher peaks in the desert ranges of the Great Basin (Loope 1969).

Alpine ecosystems are poorly developed in the Cascade Range of the Pacific Northwest, where much of the zone above timberline is occupied by glaciers, snowfields, and bare rock (Franklin and Dyrness 1973). The Sierra Nevada alpine zone is more extensive, and extends south to the San Jacinto Mountains of southern California.

There are also limited areas of alpine tundra on the highest summits of the mountains in the New England region of the eastern United States (Bliss 1963).

Altitudinal Limits

Timberline, which defines the lower limit of the alpine zone, is that elevation above which erect trees do not normally grow. Timberline varies with local environment, and is more of a zone than a distinct line. In the Rocky Mountains it is located at about 3600 m in northern New Mexico (Schwan and Costello 1951), 3350 m in northern Colorado (Marr 1964), 3000 m in northern Wyoming (Johnson and Billings 1962), and as low as 2200 m in northern Montana (Choate and Habeck 1967). Alpine-like vegetation is present at 1600 m in the Olympic Mountains of Washington (Kuramoto and Bliss 1970) and in New England (Bliss 1963), but Krummholz (prostrate wind-sculpted trees) occurs above 3600 m in the central Sierra Nevada Mountains (Klikoff 1965). The general decrease in the elevation of timberline with latitude is about 100 m per degree north.

Macro Land Forms

Because the alpine zone is present only on mountains, much of the landscape is rugged and broken, with rocky, snowcapped peaks, spectacular cliffs, and talus slopes (fig. 2). However, there are also many large areas of gently rolling to almost flat topography (fig. 3). The character of any one area depends to a great extent on the degree and type of glaciation. Valley glaciers have been a major factor in the formation of the landscape of the rugged and spectacular alpine regions, and cirques, hanging valleys, and morainal deposits are common features of the landscape. The major valleys in these regions have the broad U-shaped cross section and stepwise longitudinal section of glacial valleys, and terminate in cirques. Flat to rolling terrain may be the result of smoothing by glacial action or **cryoplanation** (leveling by frost action) in areas which were unglaciated.

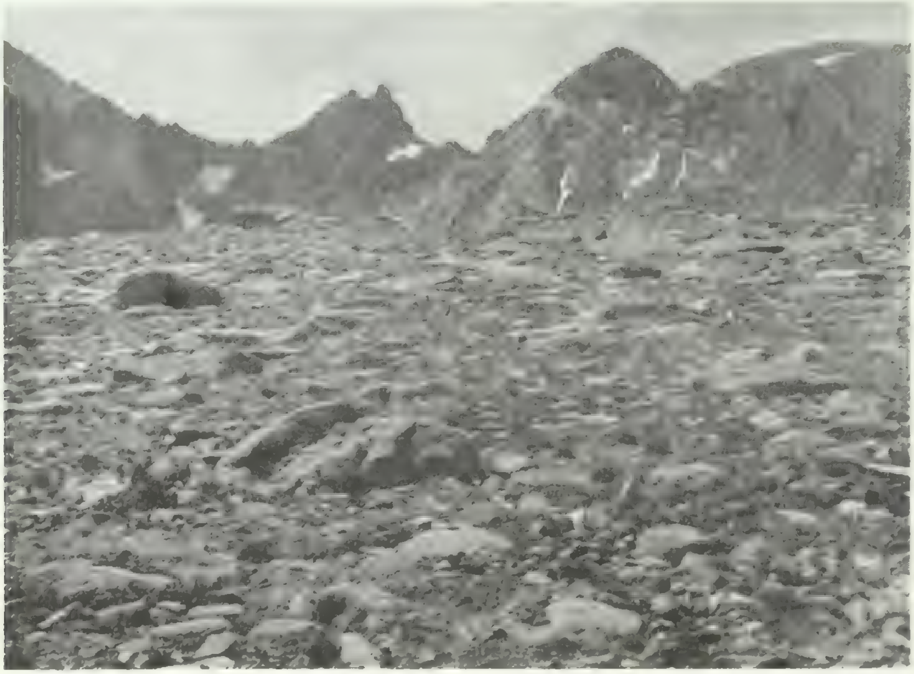

Figure 2.—Rugged alpine landscape in the Wind River Mountains, Wyoming.

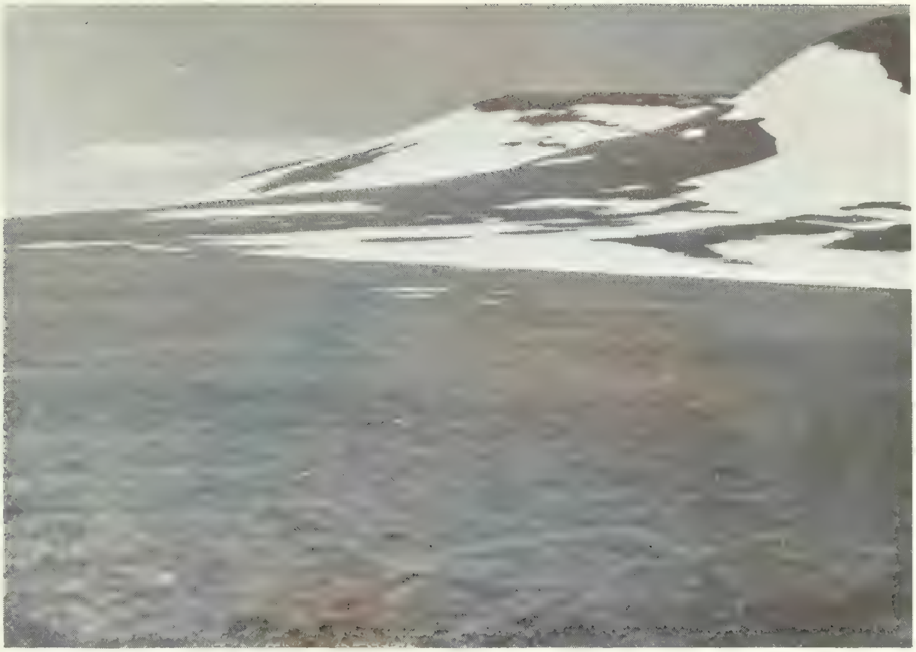

Figure 3.—Level to rolling alpine landscape in the Absaroka Mountains, east of Yellowstone Park, Wyoming.

Micro Land Forms

Even in areas of well-vegetated, gentle topography there is a considerable amount of bare rock and soil. Although some may be caused by human mismanagement, much of it is due to the natural processes of **congelifraction** (splitting of rock by frost action) and **congeliturbation** (stirring, thrusting, heaving, and sorting by frost activity). The result of these **cryopedogenic** processes is many kinds of patterned ground.

Also present as natural phenomena are lobed masses of soil **(solifluction terraces)** or rock **(rock terraces)** which move downhill as the result of viscous downslope flow of saturated soil (**soliflucion**) or the downslope displacement of material in esponse to alternate freezing and thawing **(frost creep)**. Either will move at the rate of 3 to 4 cm a year, and buried soils are common beneath them Benedict 1970).

In many otherwise well-vegetated alpine zones, ong narrow lines of rock running downslope are a prominent landscape feature. These **rock streams** ppear to be caused more by water erosion than ryopedogenic action, since a small erosion fan is sually present at the base of the slope (Retzer 1962) fig. 4).

Erosion features (fig. 5) are natural in the lpine, and it is necessary to be able to distinguish etween them and man-caused deterioration to fully interpret the results of management.

Soils

Alpine soils range from shallow, rocky, and gravelly lithosols with little or no petogenic development to boggy, organically derived peats. Mineral soils on well-drained areas with a good vegetative cover generally show considerable pedogenic development. The usual sequum (horizon sequence) is $O_2/A_1/B_2/C$. There is a high concentration of organic matter in the upper (O_2 and A) horizons, but little evidence of eluviation of clay or chemical leaching in the lower horizons.

Mineral soils in areas of restricted drainage usually have an $O_2/A_1/C$ sequence. The organic content is greater than that of the well-drained soils, but not peaty. They may have permafrost underlying them.

Organic soils develop in areas where water is ponded for long periods. The surface layer of peat may overlie water-deposited mineral material. Permafrost is usually present at relatively shallow depths.

Under the current soil classification system (Soil Survey Staff 1970), the rocky lithosolic soils would be classified at the Great Group level as **Cryorthents**. The more fully developed soils with either the $O_2/A_1/B_2/C$ or $O_2/A_1/C$ sequum would be classified as **Cryochrepts, Cryumbrepts,** or **Cryoborolls,** depending upon the kind of epipedon (surface horizon) present and the degree of development. The peaty soils would be called **Cryofibrists, Cryo-**

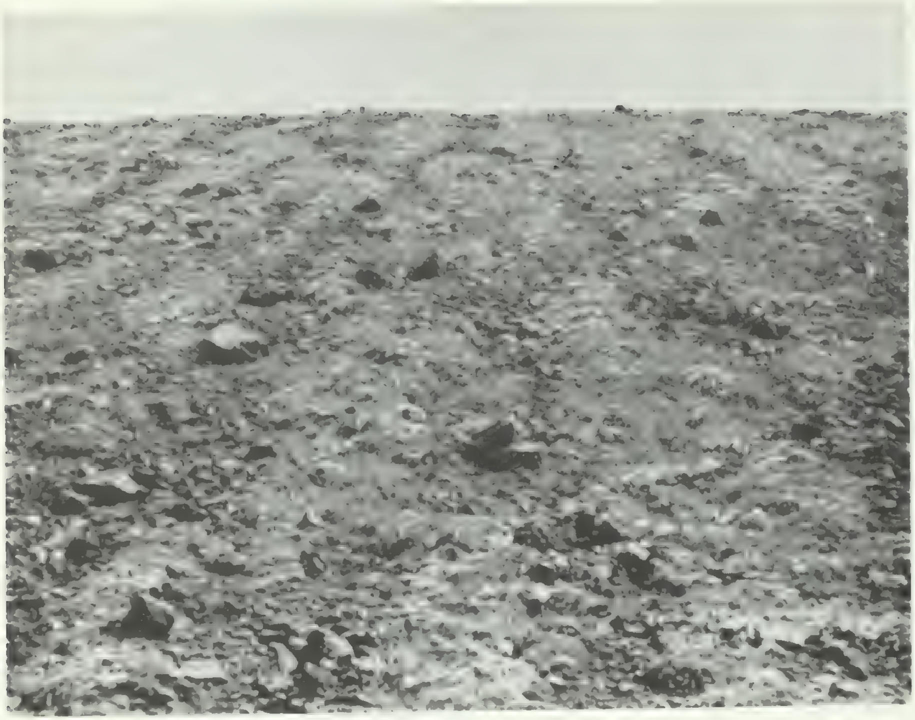

Figure 4.—Natural rock streams in the alpine zone of the Absaroka Mountains, Wyoming.

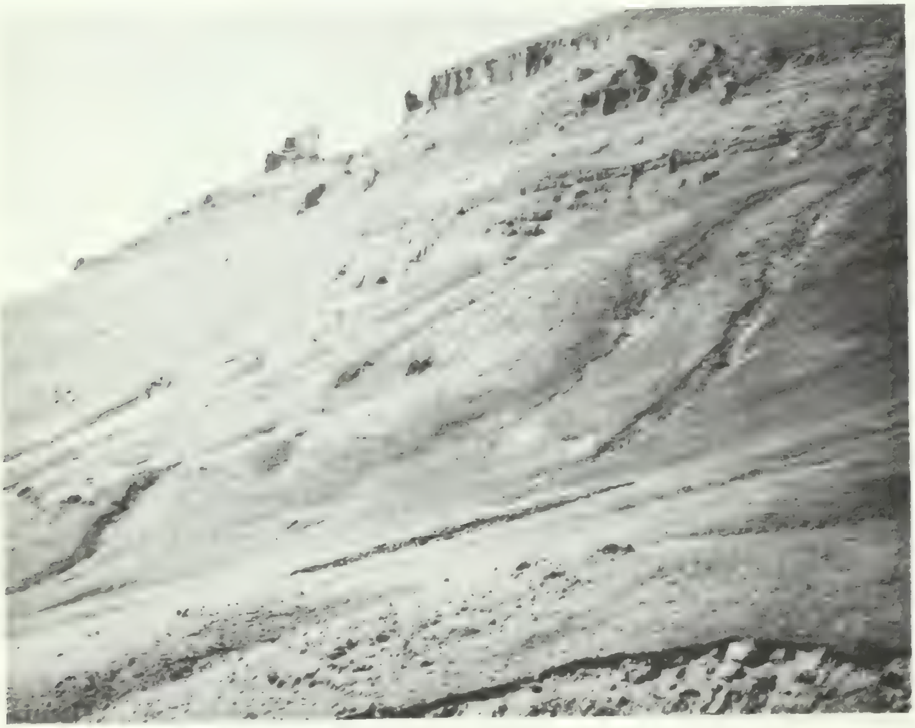

Figure 5.—Active natural erosion features on alpine rangeland in northwestern Wyoming.

saprists, or **Cryohemists** depending on the degree of decomposition of the organic material from which they were derived.

Alpine soils are in general much less uniform than the soils of lower elevation areas. Part of this is due to the variability of mountain terrain and geology, and part to cryopedogenic processes which result in a rather dynamic and unstable soil surface.

Because they are of limited extent, not arable, and generally inaccessible, little work has been done on the fertility of alpine soils of the western United States. The general consensus is that alpine soils have low inherent fertility. Low fertility may result in part from the type of parent rock from which they are formed: soils from granites are inherently less fertile than those from volcanic rocks or limestone.

Low levels of nitrogen have been considered as limiting alpine plant growth. The problem is not one of low total nitrogen content, because the surface horizons contain abundant nitrogen (ca. 20,000 to 40,000 kg/ha) in the organic form. However, there is very little (less than 0.01 percent) inorganic nitrogen as nitrate or ammonium, the form in which it is available for plant growth. The relatively low level of inorganic nitrogen is probably due to the low microbial activity of alpine soils, which is in turn a result of low soil temperatures. Psychrophilic bacteria that grow at temperatures approaching 0°C may be of major ecological importance in the nitrogen relationships of alpine soils (Faust and Nimlos 1968).

With such low levels of nitrogen, a rapid response would be expected to small amounts of nitrogen fertilizer. This has not been the case, however: up to 270 kg of NH_4NO_3 were required per ha before a plant response was noted in a study done in the alpine zone of Colorado (Faust and Nimlos 1968). Similar results were reported in the alpine zone of southeastern Wyoming (Scott and Billings 1964).

While nitrogen may limit alpine plant growth, other soil nutrients seem to be present in fairly adequate amounts (Bliss 1960). However, Smith (1966) in a greenhouse study of alpine soils using oat as an indicator plant, found a strong response to phosphorus, but no response to potassium or micronutrients. Scott and Billings (1964), on the other hand, could not show any response to phosphorus fertilization in soils collected in the same area. In their tests, however, they used alpine species (*Deschampsia caespitosa* and *Festuca ovina*) rather than oat. The problem of alpine plant-soil fertility relationships remains to be clarified.

Climate Regime

Moisture

The most important factor controlling the distribution and growth of alpine plants is soil moisture (Billings and Mooney 1968). Soil moisture, in turn, depends to a large extent on the drift patterns of the snow that result from the interaction between wind and topography (figs. 6, 7).

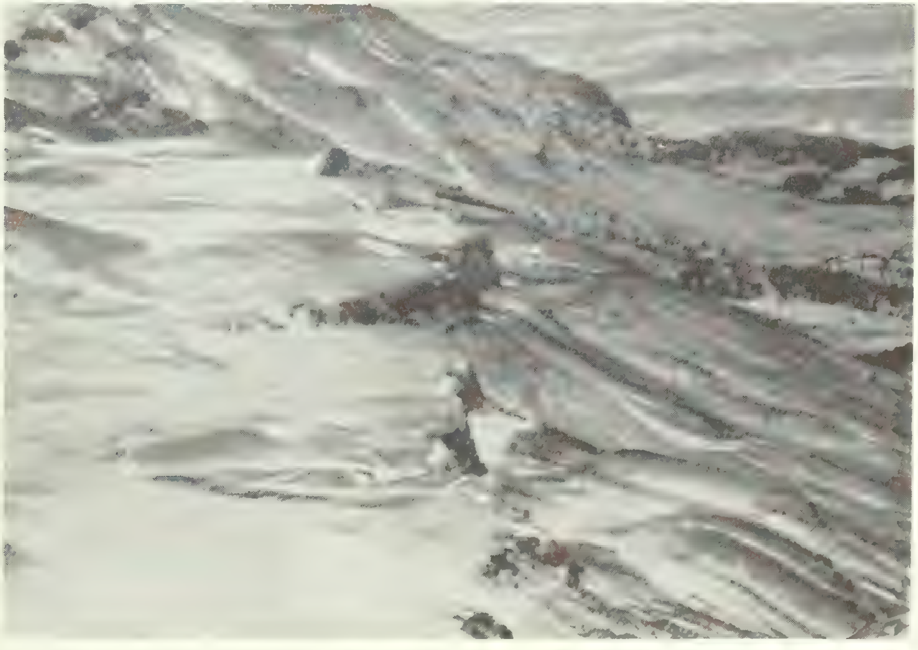

Figure 6.—Winter snow cover in the alpine zone, Nipple Mesa, Absaroka Mountains, Wyoming.

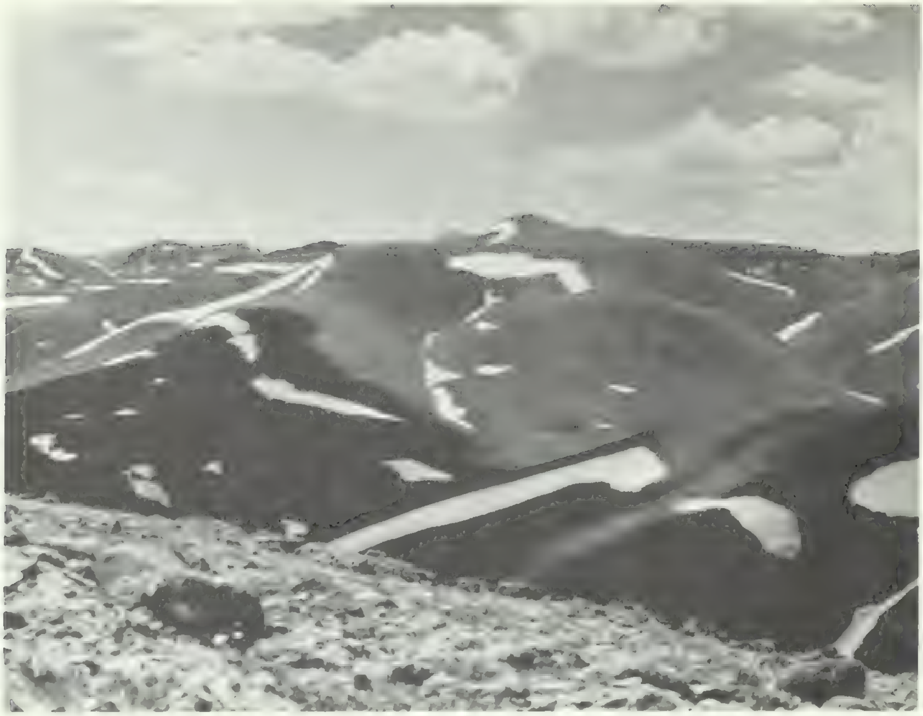

Figure 7.—Late-lying snowbanks on lee slopes are a common landscape feature of alpine rangelands well into July.

The most severe alpine environments are of two general types: (1) windswept dry ridges, and (2) late-lying snowbanks. Plants are absent in the most extreme of either of these sites. In the former, drought conditions exist both winter and summer. In the winter, strong winds remove most of the snow that falls, and water is in the form of ice; in summer, winds increase evapotranspiration rates. Plants buried under the snow have some protection from wind and abrasion, but because the water is frozen, it is unavailable to them.

Plant growth begins in most alpine species as soon as the snow melts. A few species may start growth under a thin cover of snow if free water is available at the snow-soil interface. Late release dates provide too short a growing season for good plant development, and floristic vegetational differences are obvious along a gradient from areas released from snow in the early part of the season to the areas uncovered later (Billings and Bliss 1959). Soil drought is accentuated at these later dates because of a relative lack of melt water and relatively high evapotranspiration.

Since the absence of plant development also influences soil development, soils underlying late-lying snowbanks are also poorly developed and often low in humus; hence they are also low in water-holding capacity which accentuates the drought-stress conditions.

The daily cycle of melt water from the snowbank is rather unique. It amounts to periodic irrigation, as water is released mainly during daylight hours after air temperatures rise above the freezing point. Large amounts of water flow from the lower edge of the snowbank, often as a sheet rather than in definite watercourses, and the soil and plants may be submerged for several hours during the daytime. Night temperatures are usually below freezing, with a resultant lowering or often complete cessation of flow. The generally well-drained nature of alpine soils, especially those on steeper slopes, allows the water to drain away during the night. Soil aeration improves and remains at a good level until the return of the water during the subsequent day. Thus, the soils lying below the snowbank are subjected to alternating periods of saturation and aeration; plants occupying these sites must be adapted to this situation.

Precipitation during the growing season may have little effect on the growth rate of alpine species. It often comes in high-intensity rainstorms with consequent high runoff and lack of penetration into the root zone. The degree of vegetative cover may also influence the rate of infiltration. Dense turf may preclude water reaching the soil, and in many alpine areas the cryptogam layer may effectively seal the surface of areas not covered by vascular plants. Because winds are generally strong throughout the year, water held on top of vegetation will be rapidly evaporated. On the other hand, active cryopedogenic features, with much exposed and loosely arranged bare rock, allow moisture to reach into the soil, but unless lateral drainage occurs this water will not be available for plant growth.

Water erosion is evident in the alpine zone. The effect of water in producing rock streams has already been discussed. Rill and gully erosion is common below late-lying snowbanks, especially those on steep slopes. This type of erosion is present in areas that have not been subjected to livestock grazing and is probably a natural process, although the rate of such erosion may be increased by mismanagement.

Sheet erosion occurs below late-lying snowbanks where melt water may flow over the entire soil surface rather than in a narrow watercourse. Such erosion contributes to the existence and size of nivation cirques (Retzer 1962).

Wind

The alpine zone is seldom calm. Average windspeeds of 40-50 km/hr are common during the winter, and speeds exceeding 160 km/hr (ca. 100 mi/hr) are not a rarity. Summer winds usually are not as strong, but may exceed 10 km/hr on a weekly basis and be as high as 30-35 km/hr/wk. Although windspeed is reduced near the ground, the low stature and sparse cover of vegetation on many alpine sites allows the wind to be more effective than in a taller, layered vegetation.

The effects of wind are many and varied. Wind directly influences the moisture pattern of the alpine zone by moving snow from areas where it falls to lee slopes or otherwise protected sites. The low stature of most alpine vegetation may be partially a direct influence of wind through mechanical abrasion from blowing ice, snow, and soil particles. Wind effectively reduces air and leaf temperatures and influences transpiration rates. Bliss (1960) reported that transpiration rates for tundra shrubs are directly related to windspeeds below 9.7 km/hr but inversely related to speeds above that rate, probably due to complete closure of stomata. Wind also influences pollination both directly in wind-pollinated plant species and indirectly as it affects the activities of pollinating insects. Its role in seed dissemination is obvious.

Wind-eroded land is common in alpine regions. Generally, the affected areas are found along ridgetops at the heads of valleys and in high, exposed locations (fig. 8). Areas of wind erosion are generally elongated parallel to the ridgeline and may be many meters wide. Fine soil particles are removed by the wind, leaving only the coarser sands, gravel, and rock. As this layer thickens, it acts as a mulch and retards or stops further removal of material by the wind. The eroding belts appear to widen downslope by undercutting the turf. Plants are killed both by mechanical abrasion of wind-driven particles and by desiccation within the exposed root zone. The

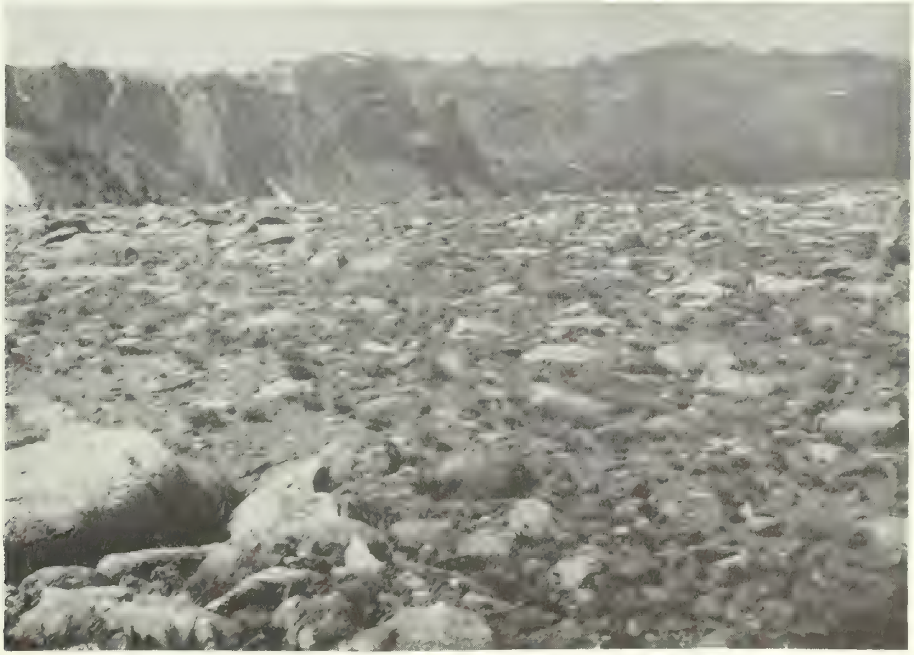

Figure 8.—Wind-eroded ridge in the alpine zone, Wind River Mountains, Wyoming.

pattern of wind erosion is generally uni-directional and dependent upon the prevailing direction of the winds. Partially because of this, plant recolonization of wind-eroded areas is slow because propagules are blown away from the area.

Wind erosion may not be completely detrimental. Soil particles removed from one area are caught by vegetation or otherwise deposited in other areas. Because these particles are primarily the clay and silt fraction, they can add to soil depth, fertility, and water-holding capacity (Retzer 1962).

Radiation

Solar radiation affects soil and air temperatures, humidity, soil moisture, and the energy flow within the alpine ecosystem. Because of their high elevation, alpine areas receive intense solar radiation on clear days during the growing season. Values exceeding 700 langleys/24 hr (1 langley = 1.0 g-cal/cm^2) have been measured, but the average value is in the range of 300 to 500 langleys because of cloudiness. On very cloudy days, values may be less than 100 langleys/24 hr even in midsummer.

Due to orographic lifting, clouds are the rule rather than the exception in the alpine zone. The general daytime growing-season cloud pattern is: Clear mornings (to ca. 1200 hr); scattered to broken cloudiness in the afternoon, often with thunderstorms; and partial clearing toward sunset.

The length of photoperiod in midlatitude alpine areas does not exceed 16 hr, and this may be effectively reduced by local topography. Because of differences in day length, the rate of incoming solar radiation in the alpine at midlatitudes is about twice that received in the Arctic, although total incoming solar radiation values during the summer are about equal (Bliss 1962).

The intensity of ultraviolet solar radiation on an alpine environment is not greatly different from that at lower elevations in the same region, although some difference can be expected from the thinner atmosphere and general lack of atmospheric pollutants of the alpine zone. Controlled experiments by Caldwell (1968) showed little or no indication of change in plant growth or development when ultraviolet light was excluded from a natural alpine community. Under controlled laboratory conditions, however, ultraviolet light alone produced minor damage to some alpine species.

An unknown factor in high-elevation alpine ecosystems is the effect of cosmic radiation on the plants. However, mountain areas receiving high-intensity cosmic radiation are usually above the normal elevation limits of most alpine species.

Temperature

The overriding environmental attribute of the alpine zone is cold temperature. The mean growing-season air temperature is often at or near 0°C. According to Warren Wilson (1957), low temperatures affect plant growth in two ways:

(1) they are near the lower cardinal point for many metabolic processes;
(2) acceleration of metabolic processes is greater at low temperatures.

The temperature regime in the alpine zone is highly variable. Not only are there pronounced shady-slope-sunny-slope variations caused by macrotopography, but also important variation is caused by microtopography. A few centimeters change in elevation caused by a hummock or depression can cause a change of several degrees, and a rock or tussock may have a distinct north-slope-south-slope temperature regime.

While the air temperature at 1 m or more above the ground may be cold, temperatures in the microenvironment at or near the ground surface may be relatively warm. This of course varies with the coverage of the plant community, angle of incidence of incoming solar radiation, nature and color of the ground surface, wind, soil moisture, and other factors. Since most alpine plants rarely exceed 20 cm in height they are adapted to take advantage of these warmer temperatures near the ground. Furthermore, because of their physiognomy, color, and inherent temperature-heat balance, the alpine plant itself possesses a **phytomicroclimate** where the temperature may be several degrees warmer than that in the immediate environment.

Temperatures in different parts of a given plant may also vary by several degrees. For example, the temperature inside a white-colored flower may exceed that of the surrounding air by 0.7°C to 2.0°C, while lilac-colored flowers have temperatures 3.4°C to 4.2°C warmer than the surrounding air (Bliss 1966).

Alpine plants not only have adapted to take advantage of the warmer microclimatic regime near the soil surface, but also have the ability to withstand sudden depressions in temperature to below freezing. Relatively high osmotic concentrations of the plant fluids may be a factor in preventing freezing damage (Bliss 1966).

High growing-season temperature may be more limiting to the distribution of alpine vegetation than low temperatures. Under high temperature regimes, carbohydrate reserves are depleted more rapidly than at low temperatures because rates of photosynthesis are lower at high temperatures (Bliss 1962).

Respiration rates do not seem to be as affected by temperature and, in fact, the dark respiration rate of alpine species is higher at all temperatures than that of lowland plants.

Floristics

The flora of the alpine areas of western North America has strong similarities to that of the Arctic and European Alps. The Rocky Mountain alpine flora appears to be more closely similar to that of the Arctic than does the flora of the Cascade-Sierra Nevada Mountains. The Sierran alpine flora is particularly unique in that it contains a relatively large number of annuals, and has very strong floristic relationships with the desert floras of the Great Basin to the east and California flora to the west (Chabot and Billings 1972).

Compared to floras of low elevations, the alpine flora is species-poor. Usually there are no more than 200 to 300 species present in the alpine zone of a given mountain range, and many of these are common to most alpine areas. Members of the grass (Poaceae) and sedge (Cyperaceae) families are almost ubiquitous in alpine areas. Additional families with wide alpine distribution are the saxifrage (Saxifragaceae), rose (Rosaceae), mustard (Brassicaceae), buckwheat (Polygonaceae), and pink (Caryophyllaceae). Many of the shrubby species are members of the willow (Salicaceae) and heath (Ericaceae) families.

Animals

While often not easily seen, wild animals are relatively abundant in the alpine zone. Many mammals utilize the alpine ranges for summer habitat. Others may be resident throughout the year, although yearlong residents usually occur also at lower elevations.

Among the common yearlong resident mammals are shrews (*Sorex* spp.), pikas (*Ochotona* spp.), hares (*Lepus* spp.), marmots (*Marmota* spp.), pocket gophers (*Thomomys* spp.), deer mice (*Peromyscus* spp.), voles (*Microtus* spp., *Phenacomys* spp., *Clethrionomys* spp., *Arvicola* spp.), weasels (*Mustela* spp.), bighorn sheep (*Ovis canadensis*), and mountain goats (*Oreamnos americana*) (Pattie and Verbeek 1967). Elk (*Cervus canadensis*) are reported to winter on alpine tundra in Rocky Mountain National Park (Marr 1964).

Because of its soil-disturbing activities, the most influential tundra mammal is the pocket gopher. These animals bring large quantities of soil to the surface where strong winds and runoff can move it downslope, covering some lower slope alpine communities. They may also consume considerable herbage (Stoecker and Bock 1971).

Large mammals using the alpine zone primarily as summer habitat include elk, mule deer (*Odocoileus hemionus*), coyote (*Canis latrans*), red fox (*Vulpes fulva*), black bear (*Ursus americanus*), grizzly bear (*Ursus horriblis*), bobcat (*Lynx rufus*), and badger (*Taxidea taxus*). Moose (*Alces alces*) occasionally enter the alpine zone, and on Carter Mountain in northwestern Wyoming, pronghorn antelope (*Antilocapra americana*) are present in the alpine tundra in the summer. Pattie and Verbeek (1967) report finding bone fragments of bison (*Bison bison*) on the Beartooth Plateau.

The most numerous large ungulate in the alpine zone is the domestic sheep. Domestic cattle, horses, and goats are also present in some areas during the summer months but are usually not deliberately herded in the alpine zone.

Smaller summertime resident mammals include porcupine (*Erethizon dorsatum*), marten (*Martes americana*), chipmunks (*Eutamias* spp.), and ground squirrels (*Spermophilus* spp.).

Many birds use the alpine zone, but the characteristic species is the ptarmigan (*Lagopus leucurus*) which is present yearlong. The water pipit (*Anthus spinoletta*), rock wren (*Salpinctes obsoletus*), and rosy finch (*Leucosticte* spp.) are characteristic of the alpine zone in summer (Hayward 1952). Often-seen birds of prey include the golden eagle (*Aquila chrysaetos*), red-tailed hawk (*Buteo jamaicensis*), bald eagle (*Haliaeetus leucocephalus*), and raven (*Corvus corax*).

Vertebrate terrestrial poikilotherms are rare in the alpine. The boreal toad (*Bufo boreas boreas*) is one of the exceptions. This species is resident in the alpine zone, and is presently being studied as an indicator of man-caused climatic changes in the San Juan Mountains of southern Colorado (Campbell 1971).

Alpine lakes and streams may often contain good endemic populations of trout (*Salmo* spp.), and char (principally brook trout) (*Salvelinus fontinalis*) have been introduced into many alpine lakes and streams with varying success. The only true alpine trout is the golden trout (*Salmo aqua-bonita*) which is native to the Sierra Nevada Mountains above 3000 m elevation (LaMonte 1946). This species has been introduced into some alpine lakes in Wyoming.

The major invertebrates of the alpine zone are Araneae (spiders), Formicidae (ants), and Diptera (flies, gnats, mosquitoes) (Hayward 1952). Apiodea (bees) and members of the Acrididae and Tettigoniidae (grasshoppers) as well as Lepidoptera (butterflies) are also common. Bees and flies appear to be the major insect pollinators in the alpine zone (Bliss 1962).

ALPINE ECOLOGY

Adaptations of Plants to the Environment

The major adaptations of alpine vascular plants, regardless of their taxonomy, to the alpine environment are reduction in height, perennial life cycle, and herbaceous habit. Reduction in height is genetically controlled, but phenotypic plasticity often allows considerable morphological variation. Along with reduced height, plants on exposed sites often have a dense, clumped appearance. This "cushion-plant" form is especially evident in exposed, windswept areas and has evolved in unrelated plant families. It enables the plant to take advantage of higher surface temperatures and minimizes the desiccating and abrasive effects of strong wind. In more protected areas (lee slopes, snowbanks, etc.) plants are taller, but rarely exceed 25 to 30 cm in height. Shrubs are equally reduced in height, and prostrate forms predominate (Bliss 1962).

The advantage of a perennial life cycle is permanence. Yearly maintenance can be low and reproduction must occur only at long intervals for survival. Many alpine shrubs are evergreen and do not have to deplete food reserves on a wholly new photosynthetic apparatus each year. Older leaves may also act as winter food storage leaves during the growing season (Bliss 1962).

The shrub life form is not especially common in the alpine. By far the majority of the plants are herbaceous perennials with large underground roots or stem storage systems. These perennials are of three main types: graminoid, leafy dicot, and the already mentioned cushion dicot. In a typical alpine situation, dicots generally have a deep primary root system with shoots proliferating near the soil surface (Daubenmire 1941).

Growth and Development

Breaking Dormancy.—Buds of alpine plants are formed during the previous growing season, usually late in the growing season. Dormancy may be broken as early as April or May or as late as August or September. The important factors are melting of the snow cover, an increase of soil and air temperatures to about 0°C, and the presence of liquid water. Relatively long photoperiod may also be important, but photoperiod has no effect without temperatures above 0°C (Bliss 1962).

Growth.—After dormancy is broken, aboveground shoots grow rapidly. Carbohydrates stored in roots and rhizomes are translocated to young shoots and leaves, both as new tissue and as anthocyanins, so that vigorous young shoots are often red. Anthocyanins are effective in absorbing ultraviolet and prevent tissue damage (Caldwell 1968).

Fast-growing alpine herbaceous plants often lack pith. A hollow stem saves materials, grows rapidly, and has the advantage of internal photosynthesis with carbon recycling. Stems may elongate several centimeters a day, and the high respiration rate provides an additional supply of carbon dioxide which is used in the hollow stem where temperature may exceed that of the surrounding air by 20°C (Bliss 1966).

After leaf expansion and development of a large supply of chlorophyll, further growth is closely tied to temperature until late in the growing season when drought, photoperiod, and carbohydrate accumulation become involved (Billings and Mooney 1968).

Photosynthesis.—Alpine plants have evolved a metabolic mechanism that allows them to capture, store, and utilize energy at temperatures close to freezing in a 6- to 10-week growing season. Photosynthetic activity occurs in alpine plants throughout most of the snow-free season during daylight hours. Net photosynthesis is low in the early season due to high respiratory rates, but increases as temperatures warm and as long as moisture is available. Maximum photosynthesis is reached at flowering. Some vascular alpine plants may carry on photosynthetic activity at temperatures as low as -6°C, and lichens may photosynthesize at -24°C (Bliss 1962).

Although data are available for only a few species, it appears that alpine plants reach photosynthetic light saturation at higher light intensities than arctic plants of the same species (Mooney and Billings 1961). Photosynthetic rates for whole plants of 4.15-13.4 mg CO_2/dm^2 (two surfaces)/hr have been reported (Billings et al. 1966). Alpine plants may be able to photosynthesize at lower CO_2 concentrations than lowland plants.

Little information is available on chlorophyll content of alpine plants. The range of 0.18 to 0.90 g/m^2 reported by Bliss (1966) is comparable to that of temperate lowland communities reported by Bray (1962). Because solar radiation is higher in alpine environments, however, photo-oxidation of chlorophyll may also be high.

Respiration.—Respiration rates of 0.15 $g/dm^2/wk$ of carbohydrate have been reported (Mooney and Billings 1961), and there is evidence that dark respiration rate at all temperatures is higher in alpine plants than in lowland plants (Bliss 1962).

The principal reserve foods in herbaceous alpine plants are starches and sugars (and in shrubs, lipids). The general carbohydrate cycle is as follows: Large amounts of carbohydrates are stored in the underground parts of alpine plants at the end of the growing season. Little of this is used during winter dormancy. After dormancy is broken, the underground reserves are rapidly depleted since respiration exceeds photosynthesis during this phenological stage. Reserve carbohydrates remain low until shoot growth is 75 to 90 percent completed. Respiration rate then drops; shoot growth slows and carbohydrate replenishment begins. Cold or cloudy weather after the rapid period of growth ceases will further deplete carbohydrate reserves, but they appear to be readily replaced after a few warmer, clear days (Bliss 1962).

Flowering.—The flowers of alpine plants are self, wind, or insect pollinated, with the first method the most common. Flowering depends on environmental conditions the year before actual flowering takes place, and both flowering and seed production decrease as environmental severity increases. Pre-formed flower buds are almost universal in both dicots and monocots in the alpine. This adaptation allows them to complete flowering even in a very short growing season. The flower bud primordia are often initiated early in the growing season, and are usually well developed by onset of dormancy. The bud can withstand very low temperatures without damage (Billings and Mooney 1968).

Reproduction.—Most alpine plants in western North America reproduce by seeds rather than vegetatively. Reproduction by seeds is more common in drier alpine sites, although layering is common in cushion plants. Vegetative reproduction by rhizomes or runners occurs more readily in mesic or wet habitats. Some alpine species also reproduce by **apomixix** (asexual seed production) and **vivipary** (germination of a propagule while attached to the parent plant). Both have survival advantages in severe habitats (Billings and Mooney 1968).

Cold growing-season temperature inhibits flowering and fruiting so that little or no viable seed is produced in many years. In other years seed crops are abundant. Because of the shortness of the growing season, seeds usually do not ripen before winter in the year they are produced. True seed dormancy is not common among alpine plants, however; the time between production and germination is environmentally imposed. That dormancy that does exist is caused by seedcoat inhibition, and can be overcome by scarification, cold temperature, light, or elapsed time (Billings and Mooney 1968).

Optimum germination temperatures are 20° to 30°C, although alternating low temperature appears to bring about higher germination success. Seeds usually germinate in early summer after snowmelt during the year following seed production. Although dormancy does not seem to be an attribute of alpine plant seeds, they will remain viable for long periods if kept at low temperature (Billings and Mooney 1968).

Little is known of the field conditions necessary for seedling establishment in alpine species, which seems to be only a sporadic and not very common occurrence. When it does happen, it appears the first growing season is devoted primarily to establishing a root system. A relatively deep taproot enhances survival by enabling the seedling to tap soil moisture at deeper levels, and providing anchorage against heaving by needle ice (Billings and Mooney 1968).

Seedlings establish both in open areas and within the crowns of other plants, particularly cushion plants (Griggs 1956). Establishment within the influence of another plant is disadvantageous from the standpoint of light and moisture competition, but affords considerable protection in needle ice or solifluction areas. Cushion plants with several other species growing within the periphery of the crown are common. Such cushions are in many respects a microhabitat.

Dormancy.—Alpine plants beyond the seedling stage are rarely killed by the onset of winter. Winter hardening is brought on by shortening day length, lowering temperatures, and increasing drought. There also appears to be a relationship between increased sugar content (raffinose) and cold resistance (Billings and Mooney 1968).

Alpine plants released from snow cover early in the growing season take longer to go through their annual growth cycle than plants of the same species that are released later in the season. The late-released plants grow faster, but are usually smaller and produce less dry matter (Billings and Mooney 1968). Sites with a relatively long growing season show distinct aspectional differences. Species that mature at different times on the long-season sites will all be in the same developmental stage at the same time on the late-release sites.

Biomass and Productivity

Most of the biomass of alpine plants is below the ground surface. Forbs appear to have a proportionately greater amount of underground biomass than graminoids, and species on mesic sites generally have more than those on xeric sites. Thus, the effect of a moisture gradient in the alpine is greater on the underground plant parts than it is on aboveground parts.

This relationship also is true for total stand biomass in the alpine zone. From 80 to over 95 percent (dry weight) of the total biomass of a mesic site may be underground (Scott and Billings 1964, Thilenius 1975), while on a xeric site the underground biomass may be only about twice that of the aboveground biomass.

A total underground biomass of 3634 g/m^2 (8.92 g/m^2 = 1 lb/ac) has been measured on a mesic sedge meadow site on Mt. Washington, New Hampshire (Bliss 1963). Thilenius (1975) recorded a total underground biomass of 7186 ± 490 g/m^2 on an alpine turf site at 3475 m elevation in the Medicine Bow Mountains. The soil depth at this site was 19.5 cm. Total aboveground biomass at the same time was 223 g/m^2, for an aboveground-belowground percentage ratio of 3:97.

The aboveground-belowground percentage biomass ratio varies with site characteristics. For example, a mesic site in the Medicine Bow Mountains of Wyoming had a total standing crop of 1400 g/m^2 with 1100 g/m^2 underground (21:79). The corresponding values for a xeric site in the same area were 750 g/m^2 belowground and 350 g/m^2 aboveground (47:53) (Scott and Billings 1964).

The majority of the aboveground standing crop is produced by relatively few species. This seems to be a general rule in alpine communities, where although 40 or more species may be present, usually 4 to 6 of them will produce more than 75 percent of the total biomass (Scott and Billings 1964, Thilenius et al. 1974).

The productivity of alpine sites varies considerably from year to year. Total aboveground standing crop of a *Geum rossii* turf community ranged from 100-150 g/m^2 over a 4-year period in the Medicine Bow Mountains (Thilenius et al. 1974). However, the contribution of forbs and graminoids remained within one or two percent of an 80:20 ratio regardless of the total standing group. Scott and Billings (1964) report a range of 14 to 348 g/m^2 of aboveground standing crop on 50 sites ranging from xeric to very mesic in the same general region. Most of the values were between 100 and 200 g/m^2.

Productivity (rate of increase in standing crop/unit time) of alpine communities on an annual basis is relatively low. Bliss (1962) gives a range of 40-128 g/m^2/yr for aboveground biomass, quite low in comparison to other terrestrial communities (Rodin and Bazilevich 1964). However, the alpine growing season is only 30 to 75 days long. When productivity is calculated on a per-day basis, alpine sites may exceed comparable rates from lowland herbaceous communities. Aboveground standing crop may increase at rates of 0.5 to 5.0 g/m^2/day during the growing season (Bliss 1966), and if root productivity is included may be as high as 11 g/m^2/day on moist sites (Scott and Billings 1964).

Phytosociology

The current concept of alpine communities regards the vegetation as a complex mosaic of community type arranged along environmental gradients. Topographic site, degree and duration of winter snow cover, and wind exposure are the major influences (fig. 9).

The combined influence of these major features of the alpine environment is basically a gradient of available moisture, and consequently temperature, and with the exception of the presence of a geological substratum of rocks with special chemical characteristics such as limestone or serpentine, the moisture gradient controls the structure, composition, and pattern of alpine communities.

It must be remembered that the gradients shown may be represented in the microlandscape as well as the more easily recognized macrolandscape. Thus phytosociological units may be present on a minute scale. As Marr (1961) so aptly put it, ". . . one's foot may rest at one instant on two dissimilar stands." This does not mean there are no large areas of phytosociologically similar vegetation units in the alpine zone, for there are, but their environmental gradients will show a minimal change across the area.

Except for certain species (such as *Oxyria digyna*) little is known of the exact autecological requirements of individual alpine species. The requirements of a given species are usually inferred from the general type of habitat where it predominantly occurs. This is complicated by the fact that many alpine species seem to have a wide autecological amplitude, and can occupy what appear to be different habitats. Usually there will be differences in size, abundance, or productivity which will allow the most preferred habitat to be distinguished. Thus, *Deschampsia caespitosa* may occur as a very small, individual plant in what appears to be a xeric habitat, but grows profusely in mesic habitats and is often a dominant species in such locations. However, because of the already mentioned features of microlandscape, it is necessary to be very careful in assessing if the site where the plant is growing is actually xeric.

Because of variations in microhabitat and the wide ecological amplitude of alpine species, designation of communities on the basis of species composition alone is difficult. Communities so determined are liable to have a great variation in composition from place to place. This has led to the current use of ordination (mathematically derived arrangement of species or sample stands along environmental gradients) as a synthesis technique in alpine phytosociology (Johnson and Billings 1962, Smith 1969a). Gradients may be single factor (light, moisture, etc.) or multifactor, such as those derived from principal component analysis.

The use of gradient analysis does not preclude a classification of alpine communities, and indeed, even the most ardent users of ordination will refer to community types, since it is difficult to describe a vegetation only by mathematical coordinates.

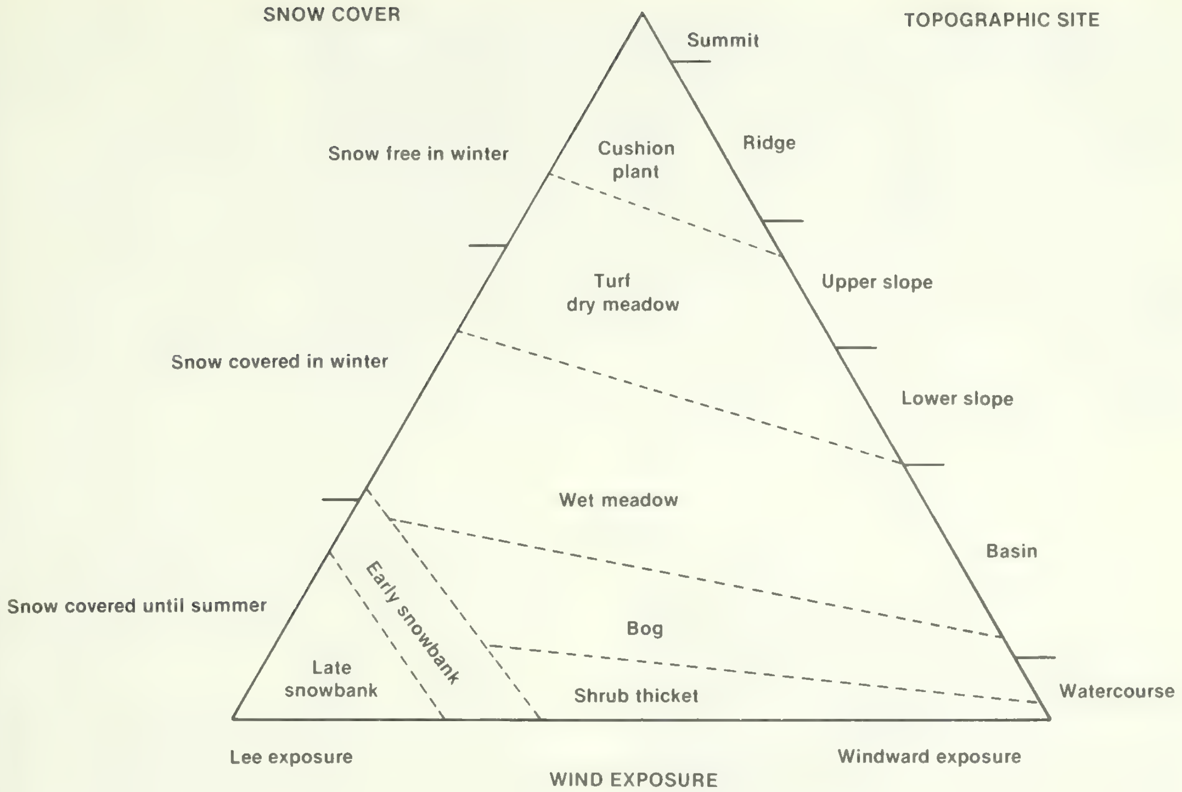

Figure 9.—Alpine vegetation as related to topography, wind, and snow cover (adapted from Johnson and Billings 1962).

While the species composition of alpine communities may be highly variable, the physiognomy of alpine communities shows a rather remarkable imilarity in response to environment. Thus, the general trend from a cushion plant community on exposed rocky ridges (fig. 10), to turfs (fig. 11), to the wet meadows, bogs and shrub thickets (fig. 12) in areas of high moisture are commonly repeated in most alpine locations.

Competition between species appears to be less intense in alpine plants than in those of lower elevation. This may be caused at least partially by the

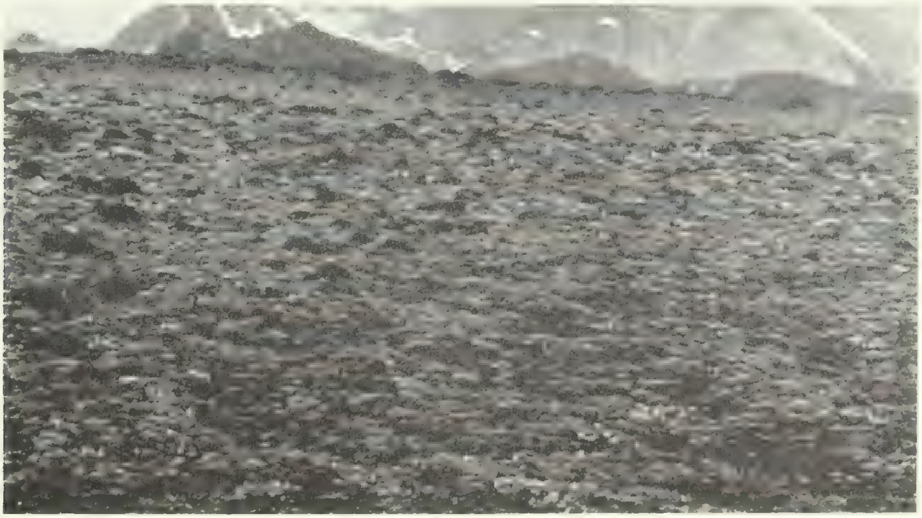

Figure 10.—Cushion plant community on exposed rocky ridge, Absaroka Mountains, Wyoming.

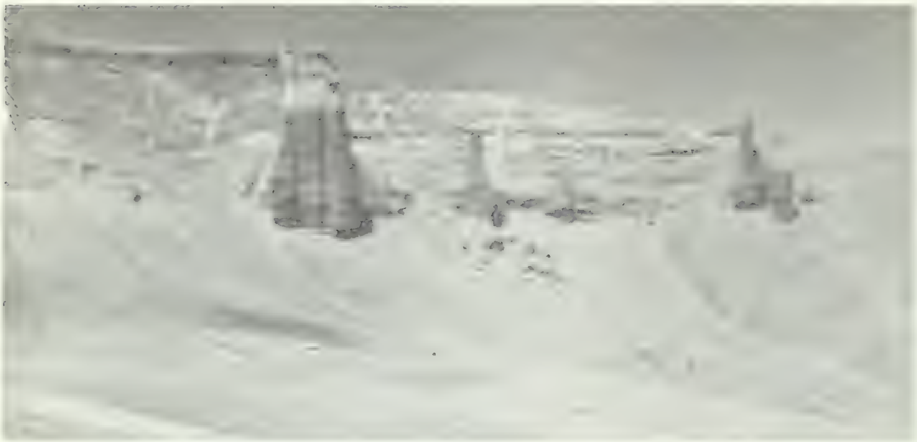

Figure 11.—Rocky alpine turf community on side slopes, Absaroka Mountains, Wyoming.

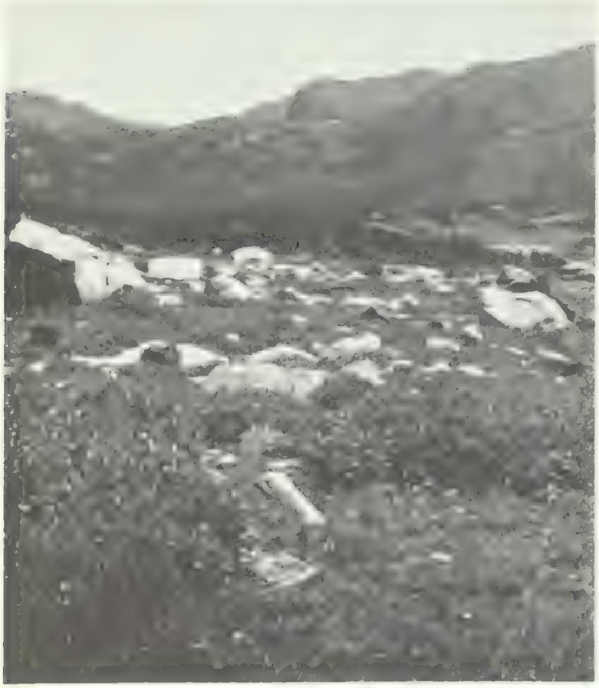

Figure 12.—Shrub thicket community, Wind River Mountains, Wyoming.

generally scattered distribution of alpine plants. In this situation, individual plants have only a very local effect on their environment in comparison to plants at lower elevation. Thus the major responses of alpine plants are to environment rather than biological influences. Lack of competitive ability may be one reason why alpine plants do not invade downward into the milder environments of lower regions.

Nevertheless, alpine species are not completely noncompetitive. Griggs (1956) has described the invasion and eventual replacement of cushions of *Silene acaulis* by other species in the alpine zone of Colorado. The changes are on a very small scale, however.

The classic concepts of climax and succession as developed in temperate, low-elevation regions do not appear to be applicable in the alpine zone (Churchill and Hanson 1958). Intense cryopedogenic action creates a dynamic instability in both vegetation and soils. Nevertheless, in areas where relatively constant environmental gradients exist for a long time, a steady-state community pattern can evolve which may be analogous to the climax community of lower elevations. Changes occur constantly within these steady-state communities, however.

Fire, an important successional influence of lower elevation zones, does not appear to be influential in the alpine zone. In general, alpine communities are usually too wet to burn, or the plants are too widely spaced to carry a fire. Billings (1969) has described the effects of fire on timberline forest (ribbon forests and Krummholz), but these are not true alpine sites. He does indicate, however, that herbaceous vegetation adjacent to or between the rather frequently burned timberline forests is very similar in species composition to the alpine tundra immediately above, and that alpine tundra may replace burned timberline forests as a result of changing snowdrift patterns.

RANGE MANAGEMENT IN THE ALPINE ZONE

In considering grazing use, two points must be kept in mind. First, the alpine zone is, for the most part, usable for grazing only during the normal 6- to 8-week summer period, and the length of this use season cannot be predicted. Furthermore, freezing temperatures, snow, and high winds can and do occur at any time during the use season. Wild ungulates using the alpine zone will move into lower zones during such critical times, but domestic livestock present a more difficult situation, and severe losses may occur.

The second point pertains to the control of domestic livestock grazing in the alpine. In the western United States, most of the alpine zone is Federal land, and the grazing is controlled by agencies of either the U.S. Department of Agriculture (Forest Service) or the Department of the Interior (Bureau of Land Management, Bureau of Indian Affairs, or National Park Service). Thus, the kind and extent of grazing reflect the policies and experience of the Federal agencies; where mismanagement has occurred or is occurring, at least part of the blame lies with them.

Concern for the condition of alpine ranges is reflected in reduction in grazing use by sheep. From 1939 to 1959, sheep numbers on alpine ranges were reduced approximately 50 percent (Wasser and Retzer 1966).

Domestic Livestock Grazing

Sheep are the principal domestic livestock using the alpine (fig. 13) zone, since normally available breeds of domestic cattle are poorly adapted to the cold, windy environment. Cattle also suffer from **brisket disease**, a congestive failure of the right side of the heart brought about by the stresses of high elevation (Alexander and Jensen 1959). Thus, range management in the alpine refers almost entirely to management for sheep.

Sheep were among the first domestic animals introduced into the New World, but up to the time of the Civil War were relatively unimportant on western ranges. During the period 1865 to 1901 sheep numbers rose spectacularly. This was the period of trail herding, when as many as 600,000 sheep were trailed from California and Oregon to stock ranges farther east and to fattening and marketing points in the Midwest (Wentworth 1948).

The early sheepmen grazed their animals yearlong, and moved up the mountains into the alpine zone—more or less following the receding snow line—for summer grazing. Sheep numbers peaked in the western United States about 1910, and have declined since (Stoddart and Smith 1955).

Many alpine ranges have been used for summer grazing continuously since the mid to late 1800's. For example, the Beartooth Plateau in northwestern Wyoming and southeastern Montana has been grazed by sheep since 1893 (Pattie and Verbeek 1967). Because of this long-term use, it is often difficult to determine what the "natural" state of many alpine ranges was.

Grazing Systems

Specialized grazing systems (deferred, rotation grazing) are being used on alpine ranges in the Intermountain Region (R-4), and are being initiated in the Northern Region (R-1) of the Forest Service. In the past, a crude form of deferred grazing was accomplished by sending sheep up the opposite end

gure 13.—Sheep grazing alpine rangelands, Carter Mountain alpine Research Site, Absaroka Mountains, Wyoming.

of sheep driveways in alternate years. This deferred the grazing on opposite ends of the range to some extent, but the center was grazed similarly in all years.

Historically and currently, most sheep in the alpine are grazed under the care of a herder. Prior to governmental control of the ranges and the introduction of grazing allotments, sheep were grazed in tightly grouped bands and continuously bedded in the same location, usually near water, for several nights in a row. These practices resulted in large losses of forage through trampling and in soil damage from excessive trailing to and from the bedground and to water.

Herding practice on National Forest lands (USDA-FS 1968a) requires the sheep to be distributed in loosely bunched (open-herded) bands and to be moved slowly, but steadily, in one direction while grazing (progressive herding). The bands should be herded by guiding the movement of the lead animals rather than herding from the rear. Excessive use of dogs is not recommended. Herding must be planned so the band reaches water only once a day, and the bands must be grazed quietly to water, not driven. A given area should be grazed over only one time during the grazing season, and the sheep should not be allowed to remain in a given area long enough to cause excessive forage utilization. One-night bedding is recommended, with the band being bedded down on a well-drained site near where they finish grazing. Salting is usually done in the bedding ground, and movable containers should be used.

Ranges grazed under these conditions seldom show excessive use of forage, and their condition may improve considerably. For example, Strickler (1961) found that 18 years of a well-conceived and directed herded system of grazing improved high-elevation ranges in the Wallowa Mountains of northeastern Oregon. Herbage production increased about 2.7 times (from 88 g/m^2 to 241 g/m^2). There was also a marked decrease in soil erosion attributed to overgrazing. Gullied meadows were healing, and the general condition of the range was considered to have increased from poor to good.

Whether or not good grazing systems are applied depends to a great extent upon the desire and experience of the herder and on the control exerted upon him. Because good herders are hard to find, a third system, called "herderless" grazing, is sometimes practiced. Under this system the sheep are turned loose on the range and allowed to distribute themselves and graze according to their own wants. Herderless grazing is not new. Jardine (1912) reported on a 5-year study on mountain range (alpine?), and the practice is normal in the mountain areas of New Zealand and Scotland.

Claimed advantages of herderless grazing include a wider distribution over the range, with the sheep scattering in bunches of 5 to 25 animals. Concentrations on bedgrounds are also minimized, and trailing damage is greatly decreased. Better weight gains on lambs also have been reported (Jones and Paddock 1966).

However, Strasia et al. (1970), in their study of herded versus unherded sheep, indicated the unherded band generally moved as a single unit although often spreading over an area of up to 2.5 km^2. These sheep tended to use the same areas for bedgrounds for long periods, and banded together into one group when bedding. The distributional behavior of the sheep may have been conditioned by herding during the rest of the year. The breed may also have influence. Rambouillets, which have a strongly gregarious habit, were used in the area studied by Strasia et al. (1970), while Jones and Paddock (1966) reported on the behavior of Columbia sheep, which may not have as strong a herding instinct.

A major disadvantage of herderless grazing is the need for fencing to limit movement. On alpine ranges, fences may be difficult to build and maintain. The tendency of unherded sheep to return to the same bedground can also be disadvantageous, as they appear to prefer steep rocky areas, which may be easily erodible (Retzer 1962).

Water is usually not a problem on alpine ranges, but if watering sites must be developed, they can be expensive. Salt must still be supplied to the sheep, but one man can do this for several bands. Collection of the sheep at the end of the grazing period could be a problem if they scatter widely. Nevertheless, large numbers of unherded sheep are "mustered" (collected) in the fall in the New Zealand Mountains where, except for lower elevations, conditions are very similar to those on alpine ranges in the western United States.

Research in progress on herderless grazing on an alpine range in northwestern Wyoming[2] indicates for the period 1965-70, total foliage cover increased 28 percent on unherded range as compared to 6 percent on an adjacent range where the sheep were herded in the normal manner. Major increases on the unherded allotment occurred in sedges (9 percent) and cushion plants (14 percent). There was no difference in the weights of lambs from the two ranges. Average weight gain was about 9 kg/lamb over a 60-day grazing period, with a maximum gain of 16 kg/lamb.

Predation may increase with herderless sheep grazing. The extent of predation on sheep is, of course, a subject of controversy and conjecture.

Because alpine ranges are often remote and on rugged terrain, few roads are present and getting heep to the range is difficult. Sheep driveways have een a common feature of many National Forests in he western United States. These driveways are sually noteworthy for the extent of range deterioation present on them. Forage may be practically onexistent, and the plants that do grow are often vorthless as forage or even poisonous. Erosion has een greatly accelerated by the trampling of many nimals over many years, and the loss of the plant over may cause greatly accelerated runoff and tream siltation. Because such range deterioration is o longer tolerated, many driveways have been, or vill be, closed. Rehabilitation of the driveways will e expensive, and in the alpine zone, at least, the echniques of rehabilitation, both cultural and iological, are not well known.

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[2] *Unpublished data on file at the Rocky Mountain Forest and Range Experiment Station's Research Work Unit, Project 1703, Laramie, Wyoming.*

Range Readiness

Conditions of soil moisture and plant developnent determine when a range is ready to be grazed. n the alpine zone, the duration of snow cover is onsidered to be the primary factor influencing the henological development of plants (Holway and Vard 1965). Growth starts as early as mid-May on now-free sites, but on areas where snow accumuates it may not start until early August. Regardless f the time growth starts, most alpine species show efinite signs of dormancy by mid-September.

On lower elevation ranges, the proper time to tart grazing may often be judged by the phenoogical state of certain species (Stoddart and Smith 955). On alpine ranges, while the time period for a iven phenological stage appears to be rather stable or an individual species, the time of initiation of a articular phase will vary considerably from site to ite, and from year to year at a given site (Holway nd Ward 1965). Thus, it appears phenology may ot be a good indicator of readiness for alpine anges.

Traditionally, sheep are turned onto most lpine allotments between July 10 and 15, where hey graze for a 60-day period. Based on the growth nd development of the plants, this appears to be a uitable time to start grazing. An earlier date would llow grazing during the period of most active rowth, which might increase the chance of rampling damage because of wet soils. A later date vould extend the grazing season to the end of eptember when the chances of heavy snowstorms re much greater. Early fall snowstorms are disdvantageous in two ways: (1) the obvious danger of igh losses of sheep, and (2) the danger of heavy rampling damage to the soil from large numbers of heep moving across areas where the soil has been oistened by the snow, but where it is not yet olidly frozen. A further disadvantage of late-season razing is the removal of preformed flower buds (see Growth and Development) and the consequent alteration of the flowering-root reserve replenishment cycle which might influence plant growth during the coming growing season.

Quantity and Quality

Quantity.—The small-scale distribution pattern of alpine plant communities and their rather nebulous nature makes it difficult to assess forage production over large areas of range. Production can vary greatly between points separated by only a few meters. The most productive sites are those with high available moisture. The least productive are freely drained, rocky ridges or other terrain exposed to cold, desiccating wind. Within this range of sites, total herbage production can vary from almost nothing to over 300 g/m^2. On intermediate sites (alpine turf), production will usually be in the range 100-200 g/m^2 (Scott and Billings 1964, Thilenius et al. 1974). However, these figures can vary as much as 50 percent from year to year, depending on the immediate growing season conditions. Production usually peaks 3 to 4 weeks after snowmelt (mid-July) and then slowly declines (Billings and Bliss 1959).

From the standpoint of grazing management, both of the site extremes mentioned above should be considered as unsuitable range: the wetter sites because of their importance as aquifers and the susceptibility of the vegetation to trampling damage, and the drier sites because of their low herbage production and the high erosion potential of the exposed regolith.

Areas with steep slopes (+40°) should also be considered unsuitable range, regardless of the degree of plant coverage, since it is doubtful if they can be grazed without damage. Lesser slopes are suitable (Schwan and Costello 1951). Large thickets of upright shrubs may contain some forage, but are often so dense sheep cannot enter without causing severe trailing or without heavy overbrowsing of the edges. Unless they are relatively open, such thickets should be considered as unsuitable range. Sheep should also be kept from snowbanks and the wet ground surrounding them. Slopes holding late-lying snowfields are also difficult to graze properly, and should be considered unsuitable range even though they may not be especially steep.

The plant production of a site will vary not only with yearly growing conditions but also with the specific composition of the site. Paulsen (1960) found turf stands dominated by *Kobresia* spp. and *Carex* spp. to average about 40 g/m^2 of total herbage (air-dry weight), while those dominated by *Deschampsia caespitosa* averaged about 66 g/m^2. Turf sites dominated by *Geum rossii* in the Absaroka Mountains of Wyoming are more productive. Average herbage production there varies from 92 to 118 g/m^2 depending upon the subordinate species present. Similar alpine turf communities in the Medicine Bow Mountains are even more productive, producing 100 to 150 g/m^2 of air-dry herbage (Thilenius et al. 1974). Thus a total herbage production of 90 to 100 g/m^2 is a reasonable value for grazable alpine turf sites.

Quality.—Although little research has been done on the nutritive quality of alpine plants, the available information indicates they provide generally high-quality forage. The most complete work was done by Johnston et al. (1968) on 21 species of plants from alpine tundra at 2200 m elevation in the southeastern Canadian Cordillera. Crude protein, calcium, phosphorus, ash, silica, and cellulose and in-vitro digestibility were determined for graminoids at the leaf, heading or flowering, ripe seed, cured, and weathered stages of growth, and for forbs and shrubs at the first three growth stages listed above. Percentages of crude protein and phosphorus of all species decreased with advancing maturity while calcium and cellulose content increased. In-vitro digestibility also decreased as the plants matured. Alpine grasses, on the average, contained about 50 percent more crude protein and 100 percent more phosphorus than grasses from lower elevations, while alpine sedges had about twice the protein and phosphorus of similar nonalpine species. Calcium:phosphorus ratios were low, and digestibility high for all species at all growth stages, and the vegetation was considered to provide a nutritious forage during the summer.

Other studies have shown that crude protein content of alpine species during the summer was adequate for lactating ewes (Smith and Johnson 1965). Golley (1961) reported average energy values of alpine plants to be higher than those from plants of lower elevations, and Bliss (1962) associated the high energy content of alpine plants with their high lipid content. However, Smith (1967) reported gross energy values of aboveground parts of alpine plants from Wyoming to be below the average values given by the other two authors. Differences in the ecosystems where the plants grew (New Hampshire and Wyoming) may account for some of the discrepancy.

Smith (1969b) tested the in-vitro digestibility of 54 species of alpine plants from the Absaroka Mountains of Wyoming. At the time of maximum standing crop there was a spectrum of digestibility ranging from 78 to 35 percent. As a group, grasses averaged 64 percent, sedges and forbs 60 percent, and cushion plants 44 percent digestibility. Strasia et al. (1970) also indicate alpine range provides a high quality diet.

Native *Trifolium* species are common on alpine ranges in the Rocky Mountains. Hamilton (1961) examined the chemical composition of three species (*Trifolium parryi, T. nanum, T. dasyphyllum*) common to the Wyoming alpine, and reported all to be satisfactory sheep forage. Crude protein at bloom exceeded that necessary for the nutritive requirements of sheep, and calcium and phosphorus were also adequate, while carotene content was considered to be excellent.

Except for some of the work of Johnston et al. (1968) nothing is known of the quality of the forage during the dormant season. While this is unimportant for domestic livestock, it may be very important for wild animals (such as bighorn sheep or mountain goats) that may winter on alpine ranges.

Preference and Utilization

Preference.—Preference of a sheep for a given forage is determined by its sense of smell, taste, and touch rather than sight (Arnold 1966a, 1966b), and will vary with the plant community, associated species, growth form and growth stage of the plants, weather conditions, intensity of grazing (both past and current), and the general activity and whims of the animal (Stoddart and Smith 1955).

The techniques by which preference is established also influence ratings. Three techniques are available: (1) examination of the vegetation directly; (2) use of fistulated animals; and (3) particularly with wild species, the use of sacrificed animals. All have disadvantages. In the first, it may be difficult to detect use because of the growth stage of the plant, its life form, and because removal of plant parts by grasshoppers, rodents, etc. or by mechanical abrasion due to wind, cannot be differentiated.

The difficulty with fistulated animals is that the effect of the fistula on the animal's habits is unknown. Samples from shot or trapped animals only reflect the forage an individual animal has consumed immediately before collection. Furthermore, the animal is removed from the population, which may alter the habits of the remaining animals, and the method of collection may disturb their normal feeding habits. Of the three, the use of fistulated animals appears to be the most certain method. To be most effective, however, a measure of the abundance or scarcity of plant species must also be obtained (Stoddart and Smith 1955).

With many variables influencing diet selection, a great deal of variation in reported species preference ratings is not surprising. Most of the reported information on sheep diet preferences does not come from true alpine range, but rather from subalpine ranges. The general consensus of these studies is that sheep generally prefer forbs. Estimates of the percentage of forbs in the diet range from a high of 89 percent (Stevens 1966) to a low of 24 percent (Pickford and Reid 1942). The low of 24 percent was established on a grass-dominated range; a value of 60 to 70 percent forbs appears to be about average.

Less information is available from true alpine ange. Johnson (1962) gave a list of preferred pecies, but did not quantify which were the most sed. He listed seven graminoids and eight forbs as eing "consistently grazed" and six graminoids and wo forbs as "usually grazed."

The most complete study of sheep forage reference on an alpine range is that of Strasia et al. 1970) using esophageal fistulated sheep. They oncluded:

1. The diet was composed of a large number of pecies, none of which were dominant. The most mportant forb species (with percentages in parenheses) were *Trifolium dasyphyllum* (14), *Polygoum bistortoides* (11); *Geum rossii* (10); *Trifolium anum* (10). Fescues (*Festuca rubra; F. ovina*) were he preferred grasses (13).

2. Overall, forbs made up 58 percent of the iet, but unherded sheep grazed less forbs (52) than erded sheep (65).

3. The sheep were more selective in their choice f individual graminoid species than of individual orb species, and the proportion of forbs in the diet as related to their relative availability.

4. The amount of graminoids consumed inreased in the latter part of the grazing season when orbs became less available due to utilization or isintegration, or less desirable due to maturity.

Even less is known about the diet preferences of ild herbivores using alpine range. The available nformation for bighorn sheep is biased toward the all or winter season, since the samples have usually een obtained from hunter-collected or winter-killed nimals. At this time the bighorns are usually not sing alpine range. This is reflected in the amount of rowse from nonalpine shrub species reported in the terature (Honess and Frost 1942, Smith 1954, oser 1962). The published information indicates at graminoids comprise 70 percent and forbs bout 5 to 7 percent or more of the bighorn diet Moser 1962). However, considering the postrowing season bias of the data and tendency of omestic sheep to use more grass in late season Strasia et al. 1970), it would not be surprising to nd forbs a much more important dietary item in he spring and summer. Work is needed on this spect of bighorn sheep food habits.

Forbs are the preferred dietary items of pocket ophers, and removal or reduction of the forb comonent with herbicides may cause a large decline in ocket gopher density (Tietjen et al. 1967). Osborn 958) found that pocket gophers grazed alpine undra on Niwot Ridge in Colorado heavily enough give it a "mowed" appearance, and Willard 960) described the "shredding" of cushion plants y pocket gophers. Paddock (1966) indicates forbs re more important than graminoids in the "hay" harvested by pika. Regardless of their special dietary preferences, it is obvious that small mammalian herbivores are an important grazing influence on alpine ranges, and must be taken into consideration in proper range management.

Similarly, the diet and effects of invertebrate herbivores need to be determined. Although some work is available on certain alpine invertebrate herbivores, such as Gregg (1947) and Taussig (1962) on ants, and Alexander (1951) on grasshoppers, much is unknown. Invertebrate microherbivores may be as important an influence on alpine vegetation as the more easily seen large herbivores.

Utilization.—Previously, 90 to 100 g/m^2 of total herbage has been suggested as a reasonable value for grazable alpine range. This is total herbage; usable forage is another thing. Proper use factors are available for only one alpine species, *Deschampsia caespitosa* (USDA-FS 1968b). As far as is known, no research has been done on the effects of herbage removal on alpine plants. This lack of information may tend to make managers conservative in the amount of use they will allow on alpine ranges. Nevertheless, studies of the effects of different amounts of herbage removal at different plant growth stages are needed for the major alpine species to establish a sound basis for determining levels of allowable utilization.

Light to moderate removal (20 to 30 percent of the herbage of the major species) appears to be a reasonable range of allowable use. This means from 200 to 300 kg/ha of forage would be available on an average grazable alpine turf site.

More important than knowing how much herbage can be removed, however, is knowing **how much should be left** for ecosystem maintenance. Approaching utilization from this standpoint provides for the physiological needs of the plant species.

Although little work has been done on the amount of forage removed by domestic sheep grazing alpine tundra, what is available suggests that, under a properly applied grazing system, actual forage utilization is light. Paulsen (1960), in his study of alpine range in the central Rocky Mountains determined an average utilization of only 7 percent. On the Carter Mountain alpine range in northwestern Wyoming for the period 1965-70,[3] the average percentages of use recorded on six classes of forage were as follows: grasses 8.0, sedges 11.1, *Geum rossii* 4.6, *Trifolium* spp. 20.3, forbs 5.0, and cushion plants 1.0. The average of all classes is about 8.3 percent, which agrees quite well with the 7 percent determined by Paulsen. Only the *Trifolium* spp. appear to receive more than very light use.

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[3] *Unpublished data on file at the Rocky Mountain Forest and Range Experiment Station's Research Work Unit, Project 1703, Laramie, Wyoming.*

The study by Strasia et al. (1970) showed *Trifolium* spp. to be one of the major dietary items of sheep grazing this same range.

Not all of the use recorded may be by domestic sheep, as bighorn sheep, pronghorns, elk, and mule deer also graze this range. While microtines are rare, invertebrate microherbivores are common, and certainly contribute to forage utilization, but to an unknown degree.

The daily forage intake of sheep using alpine range in the western United States has not been determined. Values ranging from 0.7 to 5.2 kg/day/sheep are given by Rawes and Welch (1969) for tundra sites in Scotland. The Range Environmental Analysis Handbook (USDA-FS 1968b) uses a value of about 80 kg for a sheep animal-unit month (AUM) (about 2.7 kg/day). This is higher than the average value of 1.7 kg/day calculated from Rawes and Welch (1969). However, the Forest Service "sheep" is actually a unit of ewe and lamb.

At the rate of 2.7 kg/day/sheep unit, 162 kg of forage are required for each sheep during the 60-day grazing season now used on most alpine sheep allotments under Forest Service jurisdiction. Recommended band size is from 1,000 to 1,200 sheep units (USDA-FS 1968a). Therefore, the gross intake of forage should be about 194,400 kg for a 1,200-animal herd for the grazing season. If, as determined previously, average herbage production is 1,000 kg/ha and proper use is 30 percent, then 300 kg/ha of forage are normally available and approximately 666 ha of usable alpine range are needed to support the normal size sheep band for a 60-day season. This converts to a stocking rate of 1.85 sheep units/ha/60-day grazing season or 0.54 ha/sheep unit/month (SUM). Recommended stocking rates (USDA-FS 1968b) are from 0.1 ha/SUM on range in excellent condition to 2.2 ha/SUM on range in low-poor condition. Range stocked at the rate of 0.54 ha/sheep unit/month would be considered good to low-good condition.

Range Condition and Trend

Condition.—While the condition (health) of alpine ranges is of utmost importance in judging the effects of range management, this factor appears to be poorly understood. As with other types of range, condition standards are based on the vegetative component, generally the amount of "desirable" and "intermediate" species encountered in a sample stand, and a rating of "soil stability condition class," based on the amount, extent, and type of soil erosion present.

The Range Environmental Analysis Handbook (USDA-FS 1968b) for the Rocky Mountain Region (R-2) states, "the description [of condition] is always relative to a standard or ideal for that particular range type." The problem on alpine range is how "ideal" is defined. Schwan and Costello (1951) provided a list of criteria and standards for range condition classes in the Rocky Mountain Region, and these classes appear to be the basis for the range condition scorecard standards for alpine range R-2 in the Range Environmental Analysis Handbook. When the condition classes are carefully read, they appear to better describe a continuum of site and vegetation which occurs from a mesic meadow to a xeric cushion plant community than they do a retrogression of a given type of site from a so-called "ideal" state to one with a great deal of disturbance.

The description of vegetation composition for alpine range in excellent condition most closely characterizes an alpine meadow dominated by *Deschampsia caespitosa,* although mention is also made of *Kobresia* spp. being present as a sod or turf, and *Salix* spp. being present on the better sites. According to Marr (1964), the *Kobresia* stand-type is found in areas free of snow for most of the winter, while the *Deschampsia* stand-type occurs in areas snow covered through the winter; *Salix* dominated communities are confined to semi-hydric locations. Thus, three quite different alpine plant communities growing in different environments are combined in the standards for excellent-condition range.

The remaining condition classes are supposed to define the extent of retrogression from the "ideal." Yet, the "good" condition description most aptly applies to the ecotone between mesic alpine meadow and alpine turf; "fair" condition the true alpine turf community usually dominated by *Geum rossii*; "poor" condition the transition between turf and cushion plant communities; and "severely depleted" the cushion plant community of exposed, xeric sites or a community present under very late-persisting snowbanks. Thus, there definitely appears to be confusion between the health status of the range and the kinds of range present on different sites. If the standards for an alpine meadow community are applied to a cushion plan community, the latter must inevitably be classed in poor or severely depleted condition. Regardless o management, it is very unlikely a cushion plan community will develop into an alpine meadow community. An area of range classified as poo under the present standards may be, for its site, in excellent condition.

The classification of different alpine plan species as "desirable," "intermediate," and "leas desirable," brings up the question, desirable fo what purpose? The implied answer is, desirable both for protection from soil erosion and as forage. Th Range Environmental Analysis Handbook indicate graminoids are best adapted to holding the soi because of their rooting habits and because the produce effective litter. However, alpine forb species also have very extensive root system

Daubenmire 1941) and may have excellent soil-olding ability, while cushion plants provide xcellent protection for the soil surface beneath hem. Furthermore, that "grasses produce more ffective litter [than forbs]," must still be deternined in the alpine zone (and in other range types, or that matter). It should be remembered that lpine communities on less than mesic sites are often orb dominated. Examples are *Geum rossii* turf Scott and Billings 1964), *Artemisia scopulorum* arden (Willard 1963), and *Dryas octopetala* teraces (Bamberg and Major 1968).

From the standpoint of forage, the present lassification of desirability is also of doubtful value n the light of more recent knowledge. For example, oth *Geum rossii* and *Polygonum bistortoides* are lassed as "least desirable" species. Yet Strasia et al. 1970) show these to be major items in the diet of lomestic sheep using alpine range, and "desirable" pecies such as *Deschampsia caespitosa* only a ninor diet item. This does not necessarily mean *eschampsia caespitosa* is poor forage, but rather it s a low-preference forage in the area studied; in nother area it may be highly preferred. Preferences eed to be determined before classifying any species n a given value category.

To properly assess the validity of the present oil stability condition classes, the very dynamic ature of the alpine ground surface must be careully considered. This factor, discussed earlier, need ot be repeated here except to say the normal rocesses of cryopedogenesis and natural erosion an cause many of the features listed as representaive or retrogressing soil stability in the Range nvironmental Analysis Handbook. That the ctivities of mismanaged livestock can also cause or ncrease such erosion features is not questioned; but hat such features are due only to mismanagement nust be carefully determined, especially in the lpine zone where they are common landscape eatures even on range never grazed by domestic nimals. Areas with high erosion, or erosion potenial, should be considered as unsuitable range egardless of the cause of the erosion.

Trend.—Range trend is defined as a change in ondition over time, and is usually determined by naking measurements at intervals of several years often 5 years) with little or no assessment during ntervening years. Regardless of the suspect nature f the condition assessment criteria expressed bove, it appears that such time-separated measurenents can neither validly express changes, nor ttribute any changes that might be measured to ange management. This is particularly true on lpine ranges, where seasonal growth varies greatly nd active erosion is normal and commonplace. To alidly assess trend, measurements must be made at early intervals and take into account the current growing conditions along with site differences and management.

It may also be possible to make measurements at very long intervals (such as Strickler 1961) so that short-term variations are masked, but waiting 20 years to determine if correct management is being used is probably not feasible.

Forest Service policy, as set forth in the R-2 Range Environmental Analysis Handbook, is to reread transects at intervals which fit local conditions; no set time interval is prescribed.

Recommendations.—Prerequisite to understanding alpine range condition and trend is a thorough understanding of alpine ecology, and how it varies from the ecology of lower elevation rangeland. Knowledge of alpine geomorphology is included in alpine ecology, especially with regard to the processes of congeliterbation and other cyropedogenic processes. A sound ecological classification of alpine range is also needed. This classification should determine the environment-site-vegetation units present in the alpine zone, and measure the within- and between-year variations of the units to define the limits of normal variability.

Information of this type would be acquired both on areas grazed by domestic livestock, and areas protected from or never grazed by livestock, if the effect of grazing is to be determined. Measures of the climatic environment must be included along with site features (topography, geological substratum, kind and duration of snow accumulation). Measures of the vegetation alone will not provide a suitable basis for classification because of the nebulous nature of alpine plant communities.

Some work on the classification of alpine communities in relation to site and environment in the Rocky Mountain Region is available, particularly in the Colorado Front Range (Osborn 1958, Willard 1960, Marr 1961); much of the recognized work has been done in Wyoming (Johnson 1962, Johnson and Billings 1962, Smith 1969a). Work is currently in progress on a classification of alpine range in the Absaroka Mountains (Thilenius and Smith [in press]).

Condition and trend standards for alpine range in the Intermountain Region (R-4) are based on the work of Lewis (1970), and many of the above comments do not apply. Lewis very clearly recognized the differences between range site potential and range health, and appreciated the unique features of the alpine soils. The Southwestern Region (R-3) uses the R-2 standards, but has modified them in light of Lewis' work. Alpine range is not recognized in the Pacific Southwest (R-5), and the Pacific Northwest (R-6) (personal communication, Regional Range Staff Officers).

Geographic limits and variations in units must also be defined. It is useless to try to apply standards determined for the *Kobresia* turf community of the Colorado Front Range to the conditions in the Absaroka Range of Wyoming, since the *Kobresia* turf community does not occur there. Thus, it may be necessary to define standards for individual National Forests, rather than Regionwide.

Finally, the Parker loop transect (Parker 1954) used to measure the vegetation component apparently does not do the job it was supposed to do (Hutchings and Holmgren 1959, Francis et al. 1972) and needs revision.

Measurement of range condition and trend is the epitome of applied ecology and is the basis on which the management program is judged. Knowledge of management effects on alpine range is of utmost importance, and good standards are essential.

Range Improvement

Range improvement refers to: (1) the use of manipulative processes such as herbicides, fertilization, and seeding, and (2) structural additions such as fences, water developments, and trails or roads. Little information is available on the latter since they have not been needed on alpine range to any great extent under the current system of herded sheep management. With the introduction of unherded grazing for sheep, both fences and water developments may become necessary.

On the Carter Mountain Alpine Range Research Area in northwestern Wyoming, a standard Forest Service four-strand barbed wire fence is used to limit the movement of the unherded band. This fence has withstood alpine conditions since 1965, with only the usual maintenance by the permittee. Duran and Kaiser (1972) estimate a cost of $2,500/km for fences on alpine range.

Three water developments have been installed at Carter Mountain to improve distribution of the unherded sheep. These consist of a fenced spring area with a steel culvert for a spring box, plastic pipe for waterlines, and commercially available metal troughs. The only unusual part of this installation was that all materials were air-lifted to the sites by helicopter. While expensive, the use of helicopters to ferry construction materials saved a great deal of time and resulted in much less disturbance than if ground vehicles or horses had been used.

Road access to alpine ranges is limited, and the repeated use of sheep driveways is highly destructive. Because of the terrain, even trail construction is very expensive. A foot trail built to Forest Service specifications at the Carter Mountain site, which rises about 300 m in elevation in 2.9 km cost $11,000 in 1964. It requires yearly maintenance.

A bulldozed road built for oil exploration purposes at the Carter Mountain site is a source of considerable erosion. Attempts to reseed the road have been unsuccessful, and natural revegetation is almost nonexistent.

Griggs (1956) reported similar results on a road across alpine tundra in Colorado. Harrington (1946) attempted to revegetate the cutbanks along Trail Ridge Road in Rocky Mountain National Park with transplanted strips of alpine sod. Marr (1964) reported that after 25 years most of the sod strips were still separated by almost bare soil. Thus, the proper construction and maintenance of roads in alpine terrain challenge both the engineer and the ecologist.

New construction on the Beartooth Highway which traverses a large portion of alpine range along the Wyoming-Montana border is being contemplated (personal communication, Shoshone National Forest Staff). An opportunity for research into the revegetation of alpine range certainly exists there. However, a rock mulch might be a better way of directly protecting cutbank surfaces. Such a mulch would cause turbulence in the ground-level winds, and possibly increase the deposition of windborne soil particles and seeds. Determining the proper kinds and distribution of rock mulch surfaces to provide an esthetically pleasing vista would provide a challenge for landscape architects.

Some information is available on the use of herbicides to alter the composition of alpine vegetation. Smith and Alley (1966) tested 2,4-D and 2,4,5-T as possible control agents for *Geum rossii*. Both caused about a 98 percent reduction in *Geum*. The 2,4-D was recommended since it leaves less residual chemicals. In a followup study, Thilenius et al. (1974) found many other alpine forbs were also reduced by 2,4-D. Most important of these was *Trifolium parryi*, an important forage species. Grasses increased rapidly after treatment; the grass:forb ratio of the treated areas was 80:20, while that of untreated areas was 30:70. No change in total herbage was measured.

Because *Geum rossii* and *Trifolium parryi*, as well as other forbs, are important dietary items for sheep on alpine ranges (Strasia et al. 1970), and there was no increase in total herbage, such herbicide treatment does not appear to be a range improvement. An exception might be under a deferred grazing system where certain areas were reserved for late-season use. Since sheep tend to use more grass at this time (Strasia et al. 1970), an increase in the grass available to them might be beneficial. The deleterious effects of herbicides on the food supply and population density of pocket gophers has been previously mentioned.

The Colorado Division of Wildlife is studying alpine range fertilization as a method of improving the forage available to bighorn sheep (Yeager 1972). The rather negative responses of alpine ranges to fertilization reported in Scott and Billings (1964) have already been discussed. Bliss (1966) found large amounts of nitrogen fertilizer would increase the productivity of alpine ranges in New Hampshire.

Billings and Mooney (1968) summarize the problem of increasing the productivity of alpine tundra through fertilization, and also provide a warning on possible ecological consequences. They stated, "The real problem in increasing tundra productivity is that most of the biomass increase is underground and not available for harvest by domestic animals or by any other means. Moreover, if one is to assume that most wild tundras are in a steady state over long periods of years, any method which tends to deplete these underground reserves is self-defeating since they are necessary to the survival of the producing plant themselves." More research is obviously needed to determine the effects of artificial perturbations on alpine ranges.

Many alpine ranges have been grazed by sheep for long periods of time, and these sheep return a great deal of organic matter and nutrients to the range in their feces. Because of the length of time some ranges have been grazed, there may have been some adaptation of the soil-plant nutrient cycle to this manuring. Cessation of use by sheep and consequent loss of the periodic addition of organic fertilizer could result in a change in plant growth. Whether this would be an increase or decrease is a matter of speculation, but it is a factor to be considered.

Large-scale weather modification may or may not improve alpine range. Cooper and Jolly (1969) state that the alpine zone is one of the most likely targets of weather modification, and that the ecological effects of weather modification are at present unknown.

Research on the impact of artificial winter precipitation enhancement (cloud seeding) on the alpine is being conducted in southwestern Colorado as part of the San Juan Ecology Project (Teller 1971). Similar research in southeastern Wyoming is known as the Medicine Bow Ecology Project (Knight 1975). A segment of that project was done in the alpine zone of the Medicine Bow Mountains of Wyoming by the Rocky Mountain Forest and Range Experiment Station (Thilenius 1975, Thilenius and Knight 1975). The objective was to provide baseline values on alpine vegetation and environment from which the ecological effects of snow increase might be measured.

Thilenius (1975) indicated large fluctuations in all subdivisions of standing crop (standing live vegetation, standing dead vegetation, litter, and total belowground standing crop) between sites and between the 2 years of study, and well-defined growth patterns could not be shown. Seasonlong average for the standing crop of live vegetation was 95.7 g/m, with over 50 percent produced by one species, *Geum rossii*. Standing crop of standing dead vegetation and of litter were about three times greater than that of the live vegetation. Average belowground standing crop was 4999 g/m^2; the percentage aboveground:belowground ratio was 10:90. The large fluctuations and different patterns of growth made it impossible to adequately determine baseline values of standing crop from which the possible effects of increased wintertime precipitation might be determined.

Integration with Other Uses

Watershed

Streamflow from the alpine is great in proportion to its area. Schwan and Costello (1951) estimated that although only about 3.5 percent of Colorado is in the alpine zone, the area produces approximately 20 percent of the State's runoff. Martinelli (1965) calculated a water yield potential at mid-June of over 1500 m^3/ha, from a 112,000 ha alpine catchment on the Front Range of Colorado.

The alpine zone is, in general, an area of high precipitation. Although much of the precipitation that falls as snow may be transported by the prevalent high winds to lower elevations, much remains in the alpine even in the summer in persisting snowbanks. Melting snowbanks can prolong streamflow throughout the summer. Porous soils and loosely compacted surface rock also promote infiltration. The tendency of alpine plants toward a high degree of water economy limits evapotranspiration losses (Retzer 1962).

Marr (1964) speculated that large-scale hydrologic engineering was inevitable in much of the alpine zone of Colorado, because these alpine areas overlook a region of high urban density and agricultural activity, both of which make near-maximum use of water available from natural runoff and transmountain diversions. Mid- and late-summer runoff, the period of greatest deficiency, could be prolonged by holding more snow in the alpine where ablation is naturally slower due to cool temperatures. Marr further speculated that controlled melting of accumulated snow (establishment of artificial glaciers) was possible. These would allow snow falling in years of plenty to be held over for use in years of snow deficiency.

Martinelli (1966) listed several possibilities for increasing the alpine snowpack. These are: (1) weather modification, (2) intentional avalanching to store snow in high-elevation shaded valleys, (3) reshaping natural terrain features to improve their snow-trapping efficiency and capacity, (4) control of snowmelt by the addition of materials to the snow surface, and (5) snow fences or other artificial wind barriers to increase the amount of snow in areas of natural accumulation, or to help shape terrain for more efficient snow storage.

All of these methods for increasing the alpine snowpack could certainly modify the alpine ecosystem and research is in progress on some of them: cloud seeding in the San Juan Mountains is operational, and snow fences were built in 1958 to increase the depth of natural snow in alpine areas of central Colorado (Martinelli 1966). Continued and intensive research is needed to define the ecological changes that might be brought about on the presently dynamic, but relatively stable, alpine ecosystems.

Some of the possibilities listed above could decrease the amount of range available for wildlife or domestic livestock by covering grazable alpine range with semi-permanent or permanent snowfields, and by increasing the moisture regime of areas adjacent to the snowfields to the point where they would be too wet to graze for most of the use season. Large artificial glaciers could affect the overall climatic regime, and possibly reduce the rather short growing season even more.

No great conflict is apparent between watershed management and **proper** range management. Because very little intensive management is practiced on wild alpine animals, proper range management, in this instance, refers to domestic sheep. Many of the alpine areas most suitable as alpine watersheds are really not suitable for grazing. These include (1) the steep sides of nivation cirques, talus slopes or rock glaciers, and exposed ridges, all of which produce little forage or have a high potential for erosion; and (2) the very wet areas below snowbanks or along alpine watercourses, which can be damaged by trampling or where the action of the sheep may cause increased siltation problems. Under proper management, such areas are excluded from use.

Wildlife

In the alpine zone, as in other types of rangelands in the western United States, range management and wildlife management are synonymous. Proper alpine range management must take into account the wild animal populations which also use the range. The question of competition between domestic and wild animals is often a matter of controversy and speculation. Because two or more species use a given range does not necessarily mean they are competitive.

The large wild animal usually considered characteristic of alpine ranges in the western United States is the bighorn sheep. The alpine zone provides much of its summer habitat, and in some localities these animals may occupy alpine range throughout the year. There is good evidence that this occupancy is forced (Smith 1954, Beuchner 1960, Moser 1962) and that, prior to intensive human-directed activity, bighorn sheep ranged through a wide variety of habitats including many at low elevations. Where possible, bighorns continue to use low-elevation habitats, especially during winter, and often yearlong (personal communication, Wildlife Staff Officer, Shoshone National Forest). Bighorn sheep are puzzling and unpredictable animals (Geist 1971). They are considered the "quality" trophy for big-game hunters in the United States (O'Connor 1973).

Bighorn sheep were apparently rather common through the Rocky Mountains in the early 19th century. A major decline in the latter part of that century has been blamed on scabies contracted from domestic sheep (Smith 1954, Beuchner 1960). Uncontrolled hunting and competition for space and forage with domestic livestock were other contributing factors.

The much improved hygiene of today's domestic sheep herds makes the likelihood of disease transmittal much less important, although it still is possible. Populations of bighorn sheep also appear to be naturally regulated by disease, principally a lung worm-pneumonia complex (Beuchner 1960). The crash population decline of the Tarryall herd in Colorado is a prime example of a sudden decline of a bighorn population due to a combination of this disease and over-solicitude in management. Beuchner (1960) lists many other areas where this kind of epizootic mortality occurred.

Beuchner (1960) states "the usurpation of alpine habitat by domestic sheep greatly reduced pristine numbers of bighorn sheep and continues to limit them." He also states that the detrimental influence of all classes of domestic livestock is greater on winter ranges than on the alpine summer ranges.

Experience on the Carter Mountain Alpine Research Area indicates bighorn sheep use the range mainly before and after the domestic sheep are present. Particularly attractive areas in early spring are the relatively level flats just above steep lava cliffs. These areas support a cushion plant community and are snowfree. The vegetation shows green foliage and flowers in May when most of the range is still dormant or snow covered. Bighorns have been observed on rough, rugged terrain below the range occupied by domestic sheep. These observations coincide with those of Beuchner (1960), who states that domestic sheep grazing in alpine areas force the bighorns into the more inaccessible and rugged terrain.

The fact that bighorns and domestic sheep do not appear to associate normally does not mean there is competition, or that removal of the domestic sheep from the alpine will cause a rise in the size of bighorn sheep populations as Beuchner seems to believe. Most sheep in the alpine are under a system herded grazing, and it may be the presence of the rder and his activities (especially shooting for edator control), equipment, horses, and dogs that e the real factors in the apparent segregation.

Personal observations in the Absaroka Moun- ns also inspected by Beuchner (1960) do not pport his contention that "indisputable overuse the vegetation" is present and due to domestic eep grazing. He uses the presence of *Geum rbinatium* (*G. rossii*) as an indication of overuse, d indicates it is "virtually" unpalatable to domes- sheep. This statement is contradicted by the work Strasia et al. (1970), which showed *Geum rossii* to an important diet item of domestic sheep. *Geum ssii* is also abundant in areas of the Absaroka ountains never grazed by domestic sheep, and hile bighorns are present in these areas they are by means abundant. Bighorns have been seen in ose proximity to the unherded sheep band on the rter Mountain Research Area.

There does seem to be direct competition for rage on lower elevation bighorn winter ranges here most of the forage has been removed by mestic livestock during the summer (personal mmunication, Wildlife Staff Officer, Shoshone tional Forest).

Because of the importance of bighorn sheep as quality trophy animal, it seems that an intensive udy is needed to determine their relationship with mestic sheep using alpine range. Knowledge is cking on the habitat preferences of bighorns on pine range, their summer diet, and in areas where ey are now forced to winter in the alpine, their tire winter ecology.

Little is known of the interrelationships of mestic sheep and other large ungulates using pine range. Mountain goats may be more of a true pine species than bighorns, but little is known of eir activities. Mountain goats appear to prefer the epest, most rugged terrain available. In contrast, ghorn sheep use this kind of terrain mainly for cape cover, and domestic sheep generally avoid it euchner 1960). There appears to be nothing pub- hed on conflicts between domestic sheep and ountain goats, perhaps because their ranges do t often overlap.

Mountain goats have been transplanted into me areas of Colorado, Wyoming, and Montana hich were outside their natural range. In these eas they tend to remain in the alpine zone through- t the year. Some concern has been expressed out the effects of this animal, both on the alpine getation itself and the possible conflict between ountain goats and bighorn sheep (personal com- unication, Region 2 Wildlife Management Staff ficer). Areas of particular concern are the Col- iate Range in central Colorado and the divide tween the Sunlight Basin and North Fork of the Shoshone River in northwestern Wyoming. Because these introductions are relatively recent, and on very rugged, inaccessible terrain, no really good information is available.

Both mule deer and elk use alpine range as summer habitat. Elk tend to use the cirque basins and alpine-subalpine ecotones to a greater extent than they do the more exposed areas. On the Carter Mountain Research Area, however, large numbers of elk antlers at elevations above 3350 m indicate a number of large bulls, at least, are on the alpine range in April or May (when antlers are shed).

Mule deer, especially large bucks, spend a great deal of time in the alpine zone of northwestern Wyoming, and have been seen on open, rolling alpine plateaus at elevations exceeding 3650 m. Beuchner (1960) indicates there is no evidence of forage competition between elk and/or mule deer and bighorns on alpine summer range, but feels there may be competition on winter ranges, particularly on those overpopulated with elk or mule deer.

The presence of pronghorn antelope on the alpine tundra of the Carter Mountain Research Area already has been described. All age classes of pronghorns have been seen, including does with kids. This use of alpine terrain by pronghorns is rather unusual, and their presence at about 3450 m elevation constituted a record for altitudinal distribution (personal communication with James Yoakum, BLM, Reno, Nevada).

Both black and grizzly bears are present in alpine tundra, but normally only in the summer (Pattie and Verbeek 1967). They may occasionally kill domestic sheep. Sheep herders will normally try to kill every bear they see. No information is available of bear predation on large, wild alpine animals. Grizzly bears may feed on microtines and ground squirrels.

The coyote and golden eagle are also present in the alpine, and are often accused of predation on both domestic and wild animals. The evidence is conflicting. Honess and Frost (1942), Smith (1954), Beuchner (1960), and Moser (1962) all indicate that coyotes and golden eagles are ineffective population control agents on bighorns. However, Rush (1940), Kennedy (1948), and Geist (1971) reported positive evidence of golden eagles attacking or killing bighorn lambs, and Brandborg (1955) related similar evidence of eagle predation on mountain goat kids. Because of their numbers and other habits, domestic sheep would seem to be more susceptible to predation by either of these animals, but good quantitative evidence is still lacking.

There are two viewpoints concerning the soil-disturbing activity of pocket gophers on alpine rangeland, both supported to a degree by research. One contends that pocket gophers have little effect, because control results in no significant improvement (Ellison 1946, Ellison and Aldous 1952). The opposite viewpoint is that pocket gophers can be very detrimental to the range and should be controlled (Moore and Reid 1951). Most of the above work was carried out in subalpine areas. Whether any of the findings can be extrapolated to the true alpine is a matter of conjecture. It does appear that, under proper management, domestic sheep should be kept off areas severely disturbed by pocket gophers because the trampling action can only aggravate an already disturbed soil surface.

Recreation

The harsh environment (even in summer) and the general inaccessibility of the alpine zone makes it unsuitable for many common recreational activities. Nevertheless, many people find the alpine attractive. These may be only a small proportion of the total recreational population, but because of the general population increase, their absolute numbers have greatly increased, particularly in areas such as the Front Range of Colorado where the alpine zone is rather easy to reach, even by automobile.

Recreational use of the alpine zone is varied. It includes consumptive uses such as hunting and fishing, and also many nonconsumptive uses such as hiking, camping, mountain climbing, photography, and ''nature watching.'' Skiing is not an important recreation in the alpine because of high winds, extreme cold, and a large amount of snowfree terrain. Many ski areas are located at the upper limits of subalpine zone. The alpine zone, however, does supply snow to these areas (fig. 14).

All direct human uses leave their impact, even ''nature watching.'' Willard and Marr (1970, 1971) have investigated the effects of human activities on alpine tundra in Rocky Mountain National Park. The greatest damage takes place at areas near roads that present panoramic views of the alpine zone, and have been provided with parking lots for the convenience of sightseers.

The main damage is due to trampling, but rock collecting, flower picking, littering, and crushing of the tundra by vehicles also degrade the immediate alpine ecosystems. Both plants and soils are damaged, and effects can be measured only after a single season of human activity. With protection from trampling, the vegetation responds favorably, and the vegetative cover will increase some. Complete recovery will take many years at best.

The extent of snowmobiling in the alpine is not known. The harsh climate and difficulty of access may limit use. Some will inevitably be driven on alpine terrain, and their ecological impact should be determined.

Four-wheel drive vehicles, dune buggies, trail motorcycles, etc., are collectively known as ORV's (off-road vehicles). These are extremely popular for recreation in the western United States. The damage that may be done by a large number of ORV's on the tundra is well documented (Ives 1974), and in many States they are wisely banned from the alpine zone (fig. 15).

Although no quantitative studies have been made in alpine tundra, Bellamy et al. (1971) conducted controlled studies on very similar Arctic tundra to determine the influence of vehicles used for petroleum exploration. They concluded damage was proportional to: the number of times a vehicle

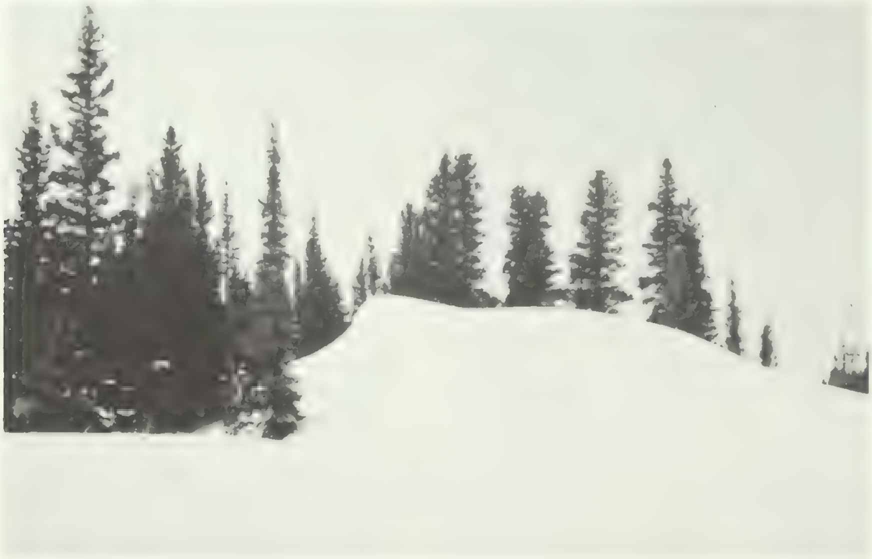
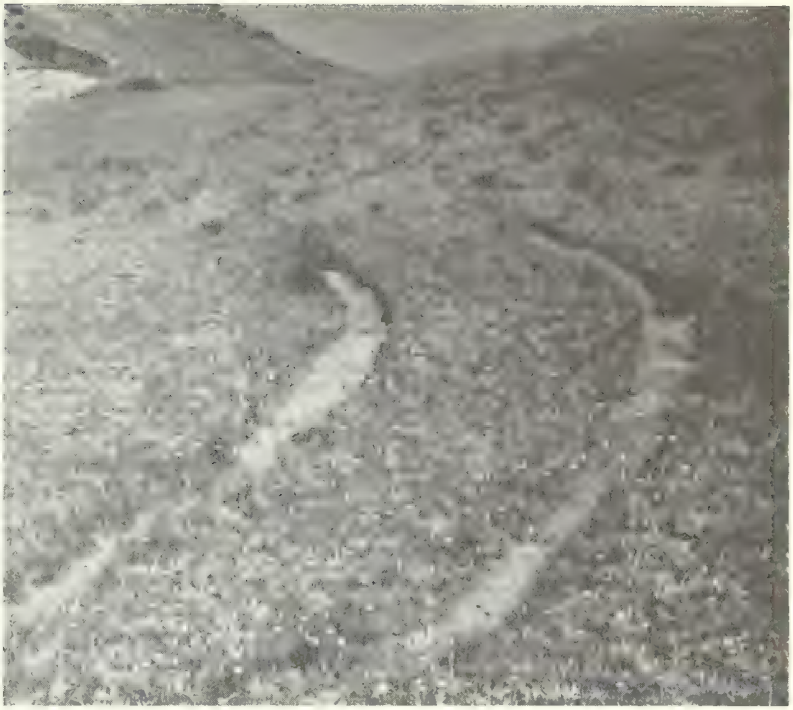


Figure 14.—Deep snowdrifts in the subalpine forest zone formed from snow blowing off alpine tundra, Medicine Bow Mountains, Wyoming.



gure 15.—Tracks across alpine tundra in the Beartooth Mountains made by four-wheel-drive vehicles.

sses over a given location, the wetness of the site, e weight of the vehicles, and the kind of vehicles ehicles with wide, flat tracks that conform to the ound surface were least damaging). They recom- ended further studies to determine the ecological pact of vehicular terrain disturbance and to vestigate the processes of regeneration of vehicle acks. All of the above statements can be applied to e alpine zone. If, as Bliss (1962) states, the alpine a harsher ecosystem than the Arctic, the influence uncontrolled vehicular travel and the slowness of generation may be even more pronounced.

Conflicts may exist between recreational use d livestock range use in some alpine areas. Burke 969) points out that damage from grazing has a fferent meaning to the recreationist than to the nge manager. To the latter, it means a decline in getation or soil. To the recreationist it means imal droppings on a trail or in a campground, uddy streams or other forms of water pollution, d unwelcome noise.

However, grazing or trampling by horses used r recreation purposes can also cause damage to itical areas. Since these are often near trails, mping spots, or major scenic attractions, they are ten very evident. Burke (1969) believed that rsonally owned horses were more likely to cause ch damage than those owned or operated by ofessional guides and outfitters, who work under permit and graze their animals away from points concentration whenever possible.

There is a great need for further research (ecological, sociological, and economic) on alpine recreation. It may be that the zone cannot withstand high concentrations of people, either under so-called "wilderness" conditions or more urbanized conditions.

Mining

One of the most evident human activities in the alpine zone is mining. Old supply roads, deserted structures, and mine tailings are a common feature in many areas of the Rocky Mountain West (fig. 16). The most evident visible alterations to the alpine landscape caused by current mining activities are the roads and exploratory excavations made by bulldozers. The problems related to roads and vehicles in the alpine apply even more to uncontrolled use of bulldozers. Roads for transportation or recreation often may be carefully designed and built to the best standards available. A "cat-road" built by a miner seeking a strike is not often so well constructed.

The problem is not confined to exploration. If a strike is made, subsequent development may also be detrimental. If the mine "proves out," structures and settling ponds are constructed and mine tailings accumulate. While the mine is in operation, attention may be paid to minimizing pollution and landscape damage, but when it is finally abandoned, the steps taken to limit pollution are no longer maintained and severe problems can occur.

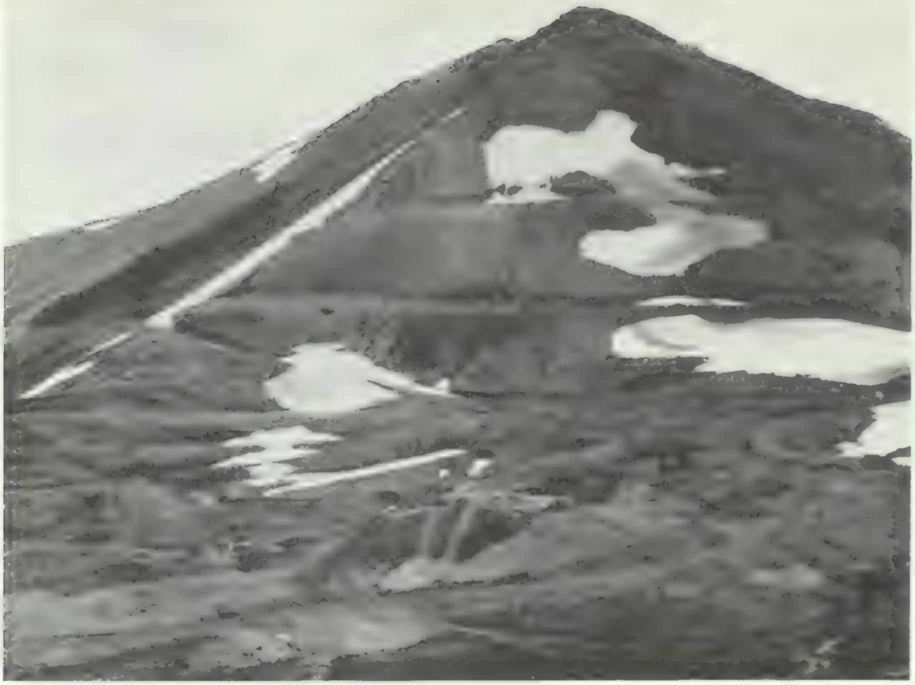


Figure 16.—Severe disturbance of alpine tundra by surface mining operations. Beartooth Mountains, Montana.

SUMMARY AND CONCLUSIONS

Because the ecology of the alpine zone is unique, range management principles and practices developed in other ecosystems must be carefully considered before they are extrapolated into the alpine. Ecological features of the alpine zone that particularly influence or limit grazing by domestic animals are: thin atmosphere, cold temperature, erratic snow distribution, strong wind, rough terrain, and naturally unstable soils.

Alpine plants generally provide nutritious forage, but distribution and abundance may vary greatly between sites, and between years on a given site. Topographic location, degree and duration of winter snow cover, and wind exposure—all of which combine to influence the available moisture and temperature regime—are the key factors controlling plants on alpine ranges.

Sheep are the principal livestock in the alpine zone since normally available breeds of domestic cattle are poorly adapted to the cold and windy environment. Many alpine ranges have been used for grazing sheep since the mid 1800's. Prior to governmental control, sheep were herded in tightly grouped bands, continuously bedded in the same location for several nights in a row, and driven to and from water. These practices resulted in large losses of forage through trampling, and in soil damage from excessive trailing.

Sheep must now be open herded and not allowed to remain in one area long enough to cause excessive forage utilization. Bedgrounds are used only for one night, and the sheep are slowly grazed to water, not driven. Ranges grazed under these conditions seldom show excessive use of forage or trampling damage. Deferred, rotation grazing systems are being used on some alpine ranges, and free-ranging sheep grazing is being studied on others.

Major problems in alpine range management are: lack of good indicators for determining range readiness, great difficulty in measuring forage utilization, inappropriate standards for determining alpine range condition and trend, and the long time-span needed to improve misused alpine ranges.

Alpine ranges are used for many other purposes besides grazing. They are the uppermost watersheds for the major western river systems, and important habitat for many wild animals, some of which (mountain goats, bighorn sheep, ptarmigan) spend a large portion of their life in the alpine zone. They have great recreational appeal, and the alpine zone usually comprises a significant proportion of the land within many western wilderness areas. Integrating alpine range management with these other uses is a major task for the resource manager.

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Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

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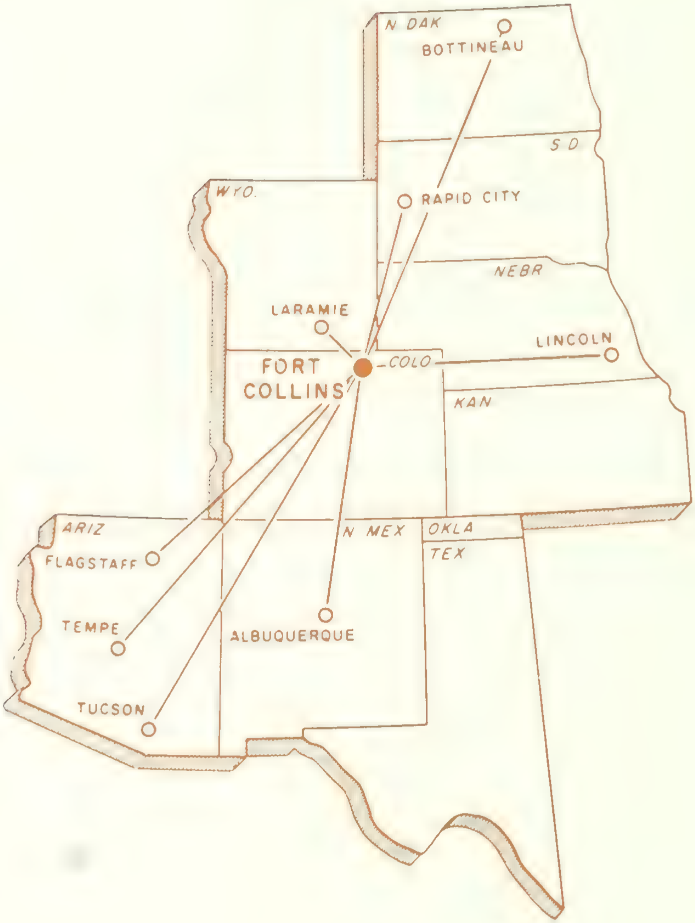
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This paper, intended to serve as a reference for managers of forested ranges, summarizes and evaluates available information about Arizona ponderosa pine-bunchgrass ranges. It covers physical-biological characteristics, factors influencing livestock production, grazing allotment conditions, and economics, and correlates grazing with other uses. Several knowledge gaps are also identified.

Keywords: Range management, grazing systems, pine-bunchgrass range.

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December 1975

RANGE MANAGEMENT AND ITS ECOLOGICAL BASIS IN THE PONDEROSA PINE TYPE OF ARIZONA:

The Status of Our Knowledge

Warren P. Clary, Principal Plant Ecologist
Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained at Fort Collins, in cooperation with Colorado State University; research reported here was conducted at Flagstaff, in cooperation with Northern Arizona University.

Contents

Page

Research Highlights 1
Physical Characteristics 2
  Geographic 2
  Climatic 2
  Edaphic 4
Ecological and Biological Characteristics 4
  Flora and Fauna 4
  Successional Pattern 6
  Phenological Development 8
  Herbage Production 10
Factors Influencing Livestock Production 12
  Improving Forage Production 12
  Nutritional Value of Forage Plants 14
  Grazing Patterns and Forage Preferences 16
  Range Condition, Grazing Systems, and Degree of Use 17
  Beef Gains 19
  Management of Livestock To Avoid Losses from Poisonous Plants 20
Grazing History, Current Conditions, and Allotment Needs 21
  Stocking Rates and Carrying Capacities 21
  Season of Grazing 22
  Grazing Systems 22
  Some Immediate Allotment Needs 22
Costs and Returns 23
  Range Improvement Practices and Grazing Intensity 23
  Economics of Cattle Ranching 24
Correlating Grazing with Other Uses 24
  Water 24
  Timber 24
  Wildlife 25
Emerging Resource Demands and Research Needs 26
  Emerging Demands 26
  Some Additional Research Needs 26
Literature Cited 27
Common and Botanical Names of Plants Mentioned 32

RANGE MANAGEMENT AND ITS ECOLOGICAL BASIS IN THE PONDEROSA PINE TYPE OF ARIZONA:
The Status of Our Knowledge

Warren P. Clary

Research Highlights

The purposes of this Paper are to summarize and evaluate the available physical, biological, management, and economic data for the Arizona pine-bunchgrass ranges. It provides information intended to help public and private managers of forest-range lands in making resource management decisions, and to help researchers make decisions concerning possible new research directions.

The information provided follows this sequence: physical-biological characteristics of the Arizona ponderosa pine type, factors influencing livestock (primarily beef) production, allotment conditions, economics, and correlation of grazing with other uses and demands. The following conclusions can be drawn from this information:

1. Considerable descriptive information is available for the Arizona ponderosa pine type. Knowledge of geographic, climatic, edaphic, and vegetation characteristics is adequate for use in reaching many management decisions.
2. The successional stages of the bunchgrass ranges appear to be sufficiently understood so that general range condition can be easily recognized.
3. A good background of range seeding information is available, and the causes of livestock losses from poisonous plants are understood.
4. A good information base on forage nutrition applicable to summer grazing has been developed for ranges dominated by Arizona fescue and mountain muhly. This base can be used as a guide to management needs when compared with the nutritional requirements of the livestock in question. Similar nutritional information should be developed for other ecological situations and for other seasons of the year.
5. Information available on the factors influencing herbage yields on volcanic soils should provide usable predictors of herbage production and how it is affected by timber overstory densities and manipulations. Similar information should be developed for sedimentary soils.
6. Potential beef gains can be predicted from nutrient consumption, and potential livestock carrying capacity can be predicted from timber density and forage composition. However, computer models capable of simulating animal distribution are needed to predict changes in **actual** livestock carrying capacity and production so that land managers will have better advance information concerning the effects of vegetation manipulation and various grazing management procedures.
7. The tree basal area that will provide maximum combined product value for joint beef and sawlog production has been determined for ponderosa pine-bunchgrass ranges to be between 45 and 60 square feet per acre.
8. No information was found that suggests that **proper** range use conflicts significantly with other forest uses, although more information is needed concerning the relationships of livestock grazing to nonruminant wildlife and general recreational values.
9. New inventory techniques are needed to provide up-to-date data on forage production and use, range condition and trend, animal numbers, and vegetation types.
10. National Forest System procedures for land use planning in some regions are now based upon assessments of land capability and sensitivity (USDA-FS 1972b). To adequately apply these procedures, information is needed on the impact of livestock use on erosion processes for the various forest and range sites.
11. Information is required concerning the effectiveness of different grazing systems as they **specifically** apply to the Arizona ponderosa pine type. It is suggested that allotment data for the Southwestern Region, R-3 of the USDA Forest Service, be intensively analyzed to document the effect of different grazing systems applied under different conditions.
12. A major effort in habitat typing has been proposed for the Southwest. This information is considered to be an essential base for future management planning, including grazing management. Three of the major differences that can be expected among habitat types are in forage production potential, initial composition of forage plants, and the manner in which the composition responds to different grazing management procedures.

13. Much of the work to be done on Arizona ponderosa pine ranges is in the area of range condition improvement. Past managerial shortsightedness often resulted in depleted ranges and impaired environmental quality. Sufficient information is available—and has been for years—to define a suitable path toward maintenance and improvement of the western ranges (USDA-FS 1936, Stoddart and Smith 1943, Sampson 1952). Where applied, existing information in the areas of forage use, livestock distribution, rest or deferment, reseeding, and control of invading plants will go a long way toward gradually getting ranges back in top shape. The difficulty, of course, is that most of these measures require added investment or intensified management, which necessitates examination of short- and long-run economic and financial tradeoffs. As these decisions can directly affect ranching profits, more information is needed on the economics and finance of range improvements. This kind of information will give managers a stronger basis for making tradeoff assessments and substantiating their decisions.
14. The day of functionalism (management for individual products or values) in managing most forest-range lands is close to being over. Range managers, particularly those dealing with public lands, need to maintain a multiple-use management perspective. All potential uses of the forested range have to be jointly considered when changes in management of a range are contemplated. Grazing practices which appreciably damage or hinder other significant products or amenities of the forest will normally have to be curtailed. On the other hand, by recognizing improvements in several products of the forest, some very worthwhile management practices may become economically defendable that otherwise would not have been if only one product had been considered. An example of this is the benefit to range, water, **and** timber production which accrues from suitably thinning timber stands.

Physical Characteristics

Geographic

Ponderosa pine[2] dominates 3,657,600 acres or 92 percent of the State's commercial forest land (Spencer 1966). The ponderosa pine forest is for the most part equivalent to Merriam's Transition Life-Zone. The lower elevation is between 5,500 and 7,000 feet, and the upper elevation between 8,500 and 9,000 feet, varying according to slope and exposure. Pure stands occur most commonly between 7,000 and 8,000 feet.

Ponderosa pine grows in many areas of the State, but the bulk of it is found in central Arizona where it occurs as an unbroken stand for nearly 225 miles (fig. 1). It is the major forest type that covers much of the Kaibab and Mogollon Plateaus. The Transition Zone is also the major forest life-zone on the higher conifer-clad mountains of the State. The southern conifer-clad mountain ranges are isolated with relatively steep topography when compared to the extensive mesas and plateaus to the north (Lowe 1964a).

Ninety-six percent of the commercial forest area is in other than private ownership. The 4 percent private ownership is the lowest proportion of any State except Alaska (Spencer 1966):

	Commercial forest area (*Thousand acres*)
National Forest	2,630
Indian	1,144
Bureau of Land Management	2
State	32
County and municipal	2
Farmer	82
Miscellaneous private	85
Total	3,977

Climatic

Southwestern ponderosa pine grows in a climatic zone where moisture is commonly in short supply. In Arizona, winds in the summer enter from the southeast, bearing moisture from the Gulf of Mexico (Kangieser 1966). The heaviest thundershowers usually occur in the mountainous region of central and southeastern Arizona.

Winter precipitation originates primarily from the Pacific Ocean (Kangieser 1966). These winter storms drop most of their moisture in the high mountains of the central and northern parts of the State. Snowfall may total 200 inches or more, but averages 12 to 94 inches.

Annual precipitation in the Arizona ponderosa pine type averages about 20 inches, with a number of areas exceeding 25 inches and some below 17 inches (Schubert 1974).

The climate in Arizona ponderosa pine differs from other interior ponderosa pine regions in that it has two pronounced precipitation periods (winter and summer). Ponderosa pine areas in eastern California and eastern Oregon have a general summer dry period with July and August being the driest; these are the wettest months in Arizona. In the Black Hills, the wettest months are May and June; these are the driest in Arizona (Pearson 1951).

Cold air masses from Canada at times cause temperatures to drop considerably below zero in the high plateaus and mountain regions of central and

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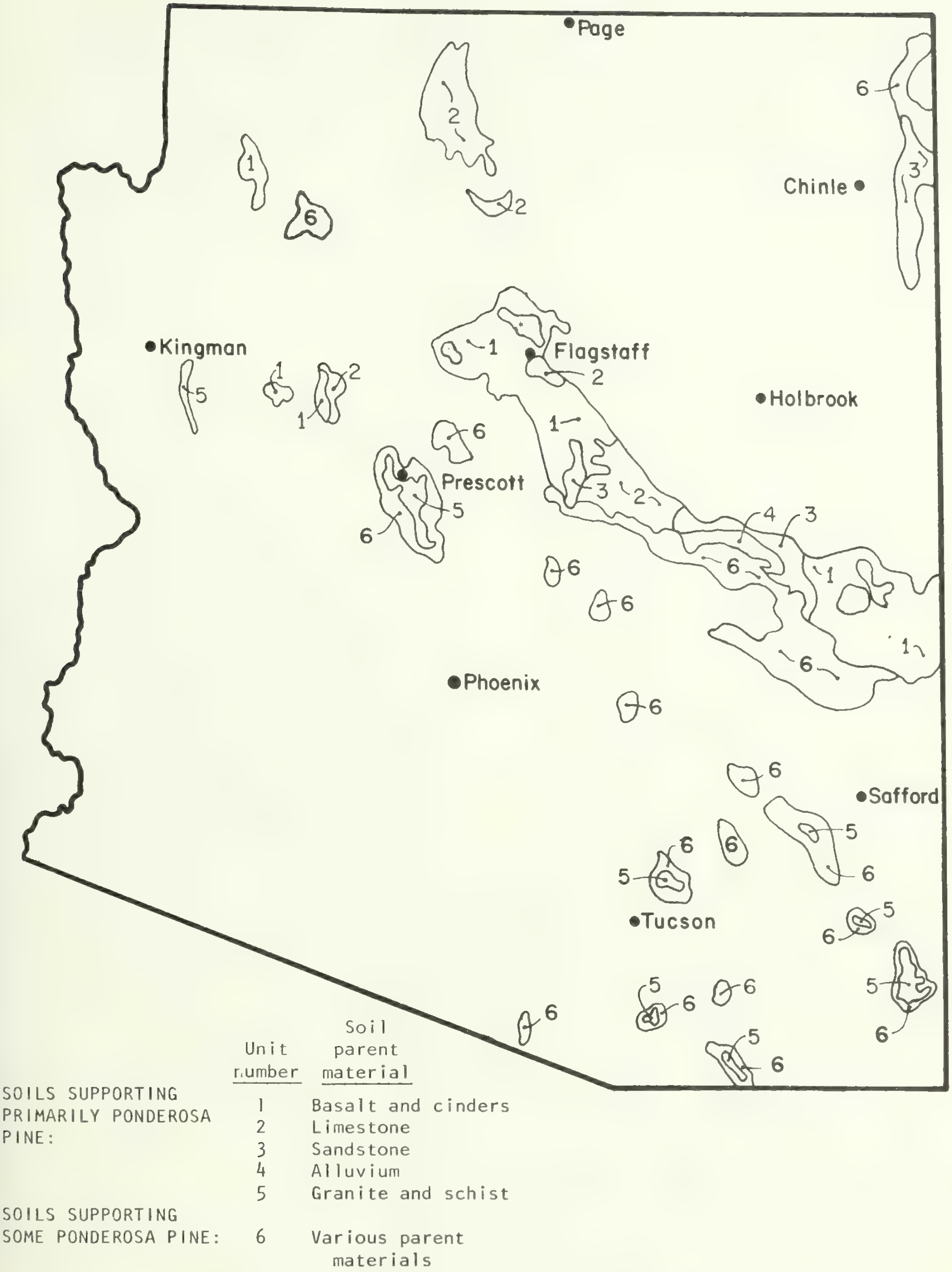
[2] *Common and botanical names of plants mentioned are given at the end of this Paper.*



	Unit number	Soil parent material
SOILS SUPPORTING PRIMARILY PONDEROSA PINE:	1	Basalt and cinders
	2	Limestone
	3	Sandstone
	4	Alluvium
	5	Granite and schist
SOILS SUPPORTING SOME PONDEROSA PINE:	6	Various parent materials

Figure 1.—Generalized soil groupings supporting ponderosa pine (interpreted after Buol 1966).

northern Arizona (Kangieser 1966). The lowest temperature recorded in the pine type in Arizona was -37°F at Fort Valley Experimental Forest near Flagstaff, on January 12, 1963, and at Maverick on January 13, 1963.

In the summer, afternoon temperatures may reach 80°F and higher, and then drop to 50°F or even down to 35° to 40°F at night. June, with few cloudy days, may have higher temperatures than July and August, which have afternoon convection storms that reduce solar radiation (Schubert 1974).

The average growing season, based on the last spring killing frost and the first in the fall, varies generally from 117 to 160 days, although extreme stations vary from 78 to 207.

Edaphic

Ponderosa pine occurs widely over soils developed from both igneous and sedimentary origin. Soil variations affecting distribution are more likely to be physical than chemical. Those factors affecting available moisture tend to be the most important (Pearson 1950). The more porous soils are the more productive, in general.

Conifer forests occupy many of the higher elevations of the State and, as previously noted, ponderosa pine dominates on over 90 percent. The soils supporting these conifer forests can be separated into two major groups: those that either (1) do or (2) do not have light-colored, leached upper horizons (Buol 1966). The first group of soils has developed principally from limestone, sandstone, and Tertiary-Quaternary gravel parent materials, while the second group has developed mainly from basalt and volcanic cinder parent material (fig. 1).

Forested soils developed on basalt and cinders in Arizona are typified by the Brolliar, Siesta, and Sponseller series. These have a dark brown to reddish-brown surface soil, 5 to 8 inches deep, which ranges in texture from clay loam to silt loam. The subsoil is usually clay textured and noncalcareous. These soils generally fall into the Typic Argiboroll category (Coconino National Forest data), although the soils in the warmer locations may be in the Udic Argiustoll category.

Forested soils developed on sedimentary formations in Arizona are typified by the Soldier and Hogg series (limestone), Wildcat and McVickers series (sandstone), and the Overgaard series (Tertiary alluvium). These soils typically have grayish-brown surface soils with sandy loam textures which may include some gravels or cobbles. An A_2 horizon several inches thick is present in the Overgaard soils. The subsoils are usually reddish-brown clays. These soils are generally Glossic, Mollic, Aquic, or Typic Eutroboralfs (Anderson et al. 1963, Buol 1966).

Other soils that support at least some ponderosa pine are primarily those on steep slopes where rapid geologic erosion has restricted profile development. These include: (1) higher elevation mesic soils developed from various parent materials, (2) shallow frigid soils developed from granite and schist, and (3) shallow frigid soils developed from volcanic materials that are located in the highest rainfall areas and are mainly vegetated by spruce and fir (Buol 1966).

Soils that typify grass parkland inclusions within the ponderosa pine elevational range are Friana (basalt parent material) and Clover Springs (limestone parent material). These are located on alluvial or depressionlike areas. The profiles tend to be heavier textured and deeper than upland soils formed from similar geologic formations. They are imperfectly drained and are classified as Typic Haplaquolls.

Ecological and Biological Characteristics

Flora and Fauna

The southwestern ponderosa pine type occurs mainly as a climax forest (Pearson and Marsh 1935) in pure irregular uneven-aged stands consisting of small even-aged groups varying in size from a few trees to several acres. This tendency toward small-even-aged groups is one of the main features of southwestern ponderosa pine forests. There are few acres in which the forests could be termed as all-aged, although there are many areas which contain stands in excess of 5 acres classified as even-aged. The irregularity in occurrence of the even-aged groups causes numerous small openings in the forest, which benefits the herbaceous plants and those consumers utilizing them.

There are several notable differences between the Transition Zone habitats of the southern mountains (south of the Salt River), and those to the north on the Colorado Plateau (Lowe 1964a). In central and northern Arizona north of the Mogollon Rim, the ponderosa forests usually contain few trees of other species, but they have a grass cover which often extends through parklike landscapes (fig. 2). On the few high mountains which rise abruptly from the Colorado Plateau, the ponderosa pine forest is present on rugged precipitous terrain more typical of the mountains in southern Arizona. The southern conifer-clad mountains are isolated ranges with relatively steep topography. These forests tend to have a complex composition of conifers and hardwoods, many of which have their areas of principal distribution in Mexico and reach their northern limits in Arizona south of the Mogollon Rim. Ponderosa pine parklands with well-developed grass areas and/or shrub understories, so typical of the north, are more often virtually nonexistent (Lowe 1964a).

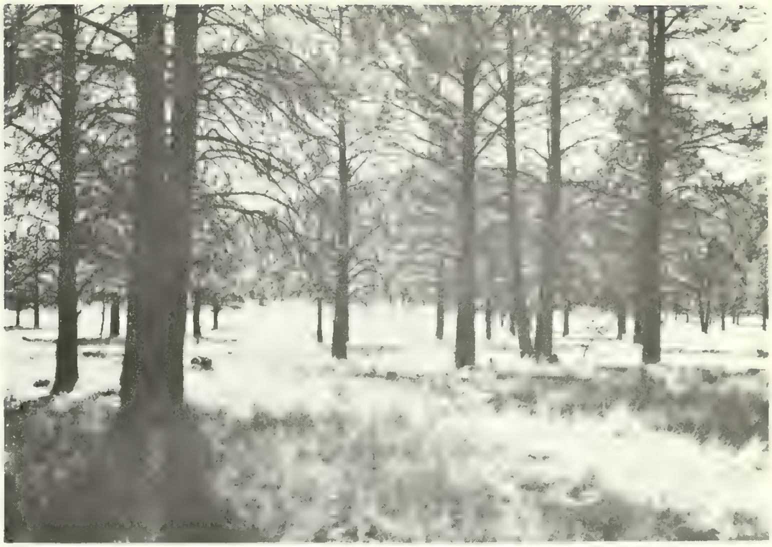


Figure 2.—Open ponderosa pine-bunchgrass range.

Gambel oak is the most common tree associated with the pines (fig. 3), and quaking aspen may be scattered or may be in large stands on old burns, usually above 7,500 feet. In the lower part of the zone, below 7,000 to 7,500 feet, pinyon and juniper may be mingled with the pines; Douglas-fir is occasional to frequent above about 7,000 feet.

Understory shrubs, in climax stands, may be essentially lacking to fairly common, though more or less widely and irregularly spaced. Some may be locally abundant, particularly at lower elevations in the forest as seen on the South Rim of Grand Canyon and on the Navajo Indian Reservation. Among the shrubs which may be found in this northern Arizona forest are Fendler ceanothus, fernbush, fendlerella, wax currant, New-Mexican locust, blueberry elder, skunkbush sumac, greenleaf manzanita, Parry rabbitbrush, big sagebrush, black sagebrush, cliffrose, Apache-plume, mountainmahogany, and littleleaf mockorange. At high elevations, the shrubs of the pine forest are more commonly species shared with the fir and spruce-fir forest: snowberry, mountain ninebark, American red raspberry, rose, common juniper, bush rockspiraea, creeping mahonia, cliff Jamesia, and myrtle boxleaf.

Perennial forbs typical of the ponderosa pine more or less throughout the State are meadowrue, American vetch, Lambert crazyweed, and Louisiana wormwood. The genera of other common forbs are: lupine, peavine, cinquefoil, yarrow, goldenrod, paintbrush, penstemon, fleabane, deervetch, groundsel, hymenoxys, milkvetch, violet, bracken, globemallow, beebalm, iris, mullein, toadflax, mock-pennyroyal, golden-pea, and others.

Grasses characteristic of the northern Arizona ponderosa pine forests include Arizona fescue, mountain muhly, screwleaf muhly, pine dropseed, mountain brome, spike muhly, deergrass, prairie June-

igure 3.—Gambel oak in a northern Arizona forest.

grass, bottlebrush squirreltail, Arizona threeawn, little bluestem, mutton bluegrass, blue grama, black dropseed, and Kentucky bluegrass (Lowe 1964a, and plant lists from Region 3, USDA-FS). *Carex* spp., mainly dryland sedges, are also present. Though common in the mountains of central and northern Arizona, Arizona fescue apparently is absent from the pine forests of the most southerly ranges. The most characteristic grasses there are two perennial muhlys, mountain and screwleaf muhly (Lowe 1964a). Descriptions and illustrations of the major forage species can be found in Judd (1962).

The herbaceous bunchgrass vegetation found beneath the tree canopy in the ponderosa pine forests also occurs in even greater densities in "parks" and "prairies" included within the elevational and geographic range of ponderosa pine (figs. 4 and 5). These openings in the forest constitute only a small portion of the total acreage within the pine type, but are locally important.

Comprehensive lists of vertebrates for the Arizona ponderosa pine type have apparently not been made, although a checklist for the entire State can be found in Lowe (1964b). Individual studies have provided information on the more common species. A description of the bird life present can be found in Carothers et al. (1973).

This vegetation type is probably best known for its populations of elk, mule deer, Merriam's turkey, and tassel-eared squirrels.

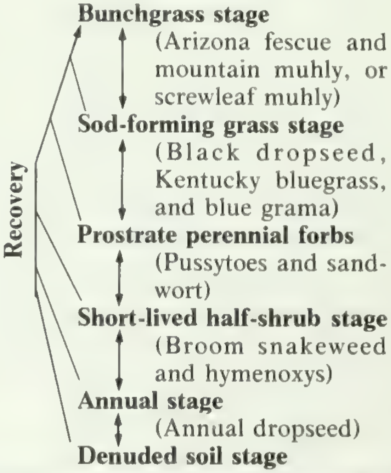
Successional Pattern

The successional pattern in Arizona ponderosa pine-bunchgrass ranges has been described (USDA-FS 1951, Arnold 1955). This pattern is typical of the major portion of the type, where ponderosa pine is virtually the only timber species present, few if any shrubs are present, and the herbaceous understory is dominated by bunchgrasses.

Deterioration from continued heavy grazing progresses through a series of stages because livestock grazing exerts a selective influence upon herbaceous plant communities. The prevailing plant life-forms of each of these successive stages of deterioration are progressively shorter lived. This sequence of life-forms (fig. 6) corresponds to the general plant strategies which provide adaptation to environmental stress and disturbance (Grime 1974). Grazing may completely denude local spots around corrals and watering places.

The following illustrates how prevailing plant life-forms (and typical species) reflect deterioration and recovery of vegetation in forest openings as livestock grazing pressure increases or decreases:

Successional stages in forest openings



Bunchgrass stage
(Arizona fescue and mountain muhly, or screwleaf muhly)
Sod-forming grass stage
(Black dropseed, Kentucky bluegrass, and blue grama)
Prostrate perennial forbs
(Pussytoes and sandwort)
Short-lived half-shrub stage
(Broom snakeweed and hymenoxys)
Annual stage
(Annual dropseed)
Denuded soil stage

Figure 4.—Small park within a ponderosa pine forest.

Figure 5.—Government Prairie west of Flagstaff, Arizona.

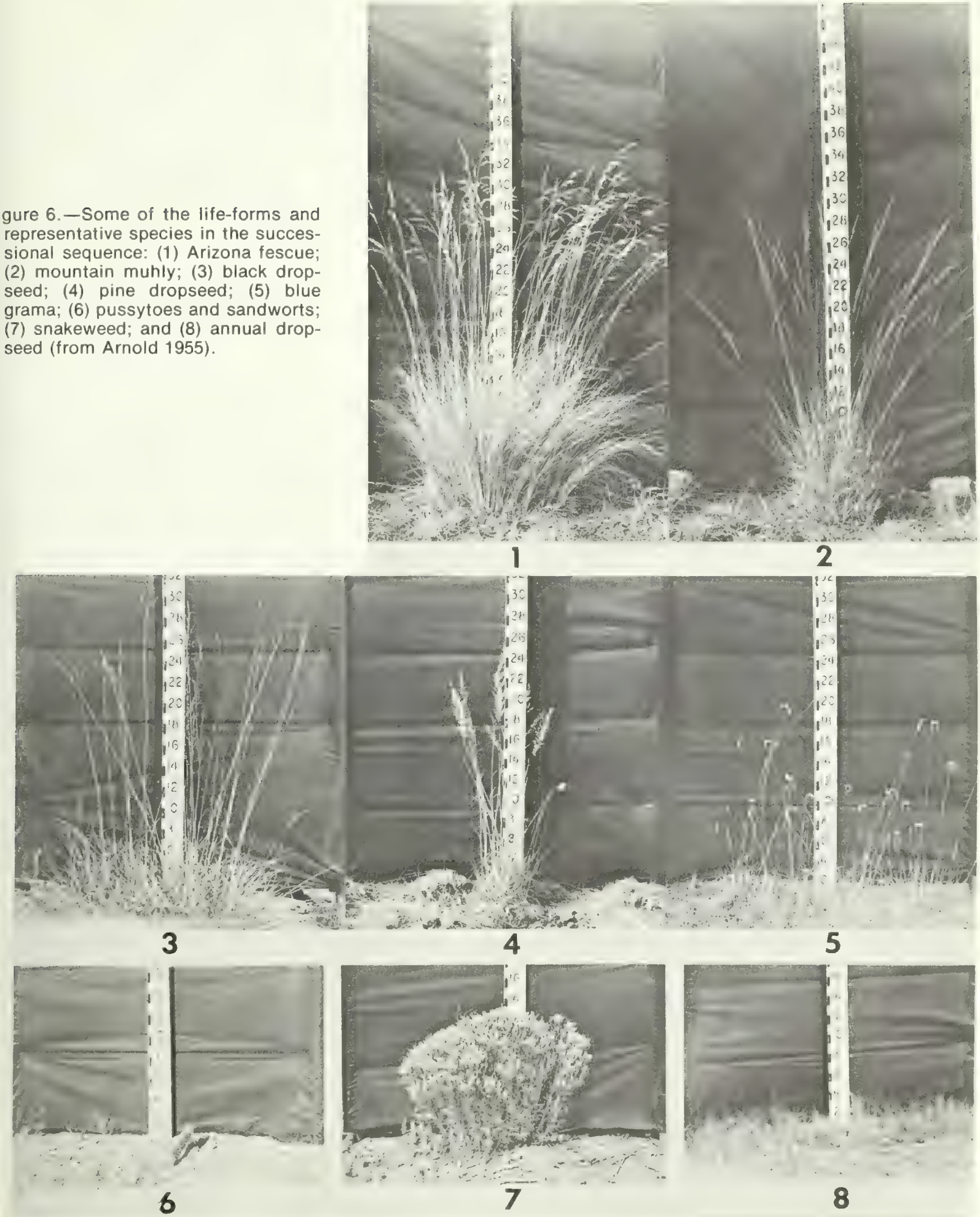


Figure 6.—Some of the life-forms and representative species in the successional sequence: (1) Arizona fescue; (2) mountain muhly; (3) black dropseed; (4) pine dropseed; (5) blue grama; (6) pussytoes and sandworts; (7) snakeweed; and (8) annual dropseed (from Arnold 1955).

A detailed list of species and their approximate places in the successional sequence is available (USDA-FS 1969).

It should be noted that, even in the bunchgrass stage: (1) grass species which either escape or withstand a high degree of grazing abuse occur as components of the herbaceous composition; (2) perennial forbs occupy a small but constant part of the total herbaceous ground cover; and (3) annuals are generally rare except for years of abundant moisture (Arnold 1950).

The course of natural recovery may or may not retrace the course of deterioration. Under reduced stocking, recovery may retrace the stages of deterioration because grazing always has a selective influence upon the vegetation. Complete natural recovery of denuded areas may require over 100 years under reduced stocking, judging from a few denuded areas in northern Arizona where recovery has only reached the half-shrub stage after 30 years (fig. 7) (USDA-FS 1951). Recovery in response to protection from grazing need not progress through successive stages, because in the absence of selective grazing, perennial grasses may become reestablished simultaneously with various perennial forbs and half-shrubs. Similarly, ponderosa pine seedlings may become established during the early stages, and the forest opening can progress directly to a forested condition.

Forms of disturbance other than grazing which typically affect the vegetation are logging, fire, and attempts at dryland farming. Each type of disturbance has its own long-term effects on the creation or reduction of forest openings and the plants growing in these forest openings. A variation of the successional sequence previously described may result when the disturbance is mechanical in nature rather than by grazing stress. The early stages will often be dominated by such tall species as lambsquarters, mullein, and thistle (fig. 8).

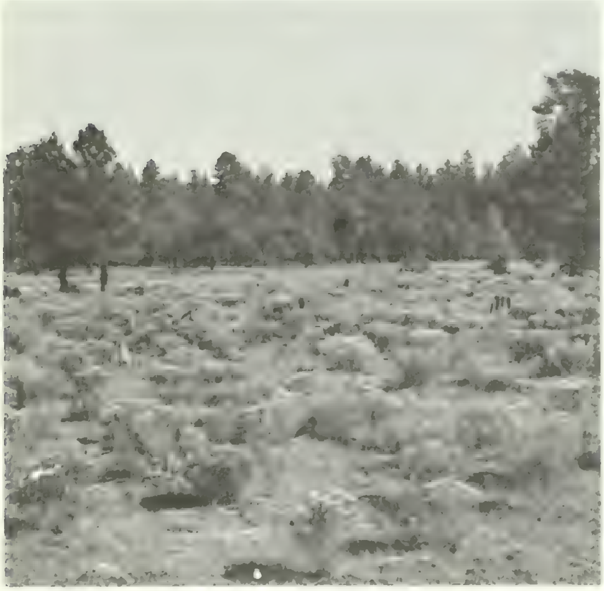


Figure 7.—Half-shrub successional stage in an area continuously grazed.

Proportional densities of the various life-forms are directly related to ecological range conditions. High densities of tall grasses in mountain meadows and high densities of bunchgrasses in pine-bunchgrass openings indicate good to excellent range conditions. Poor and very poor range conditions are characterized by perennial prostrate forbs, short-lived half-shrubs, and annuals.

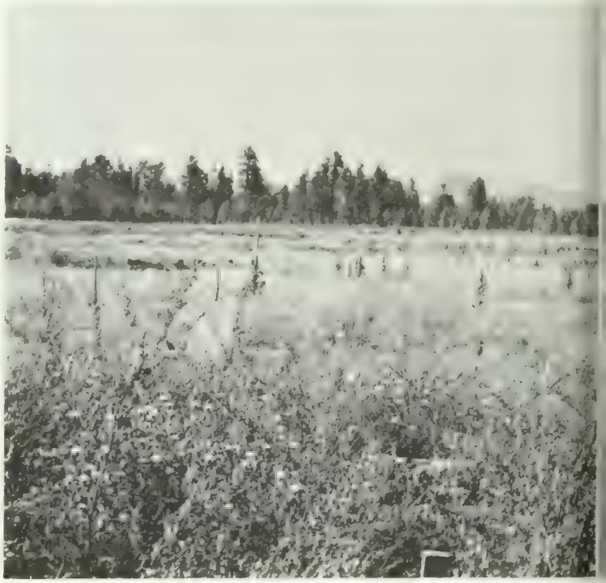


Figure 8.—Vigorous growth of pioneer species after mechanical disturbance.

Phenological Development

The phenology of the primary forage grasses of the Arizona ponderosa pine type—Arizona fescue and mountain muhly—were studied in 1963-65 (fig. 9). During this period Arizona fescue bloomed between August 2 and 19, while mountain muhly bloomed between September 7 and 25. Later information suggests that Arizona fescue may bloom nearly a month earlier than indicated above, if conditions are right. The rate of fescue growth from May through July is apparently related to precipitation falling in the prior month. Rate of muhly growth during July and August, however, appeared to be more closely related to the same month's precipitation.

Growth rate and final height of Arizona fescue are greatest in open areas, and decrease as the pine overstory increases. Mountain muhly growth rates apparently are not related to tree overstory (Pearson

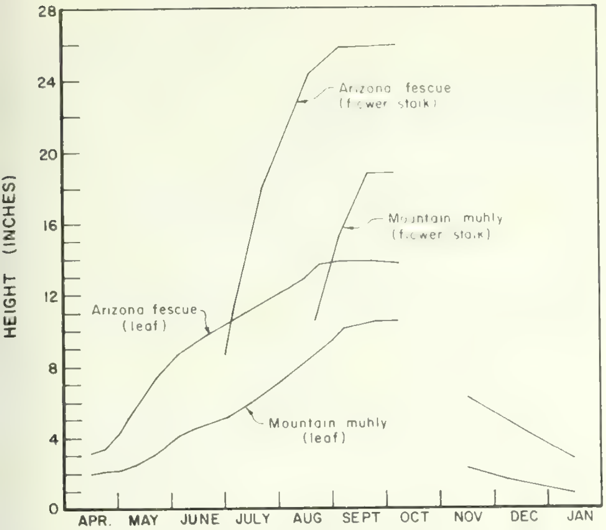


Figure 9.—Average heights of Arizona fescue and mountain muhly (after Pearson 1967b). Dashed lines indicate rapid drying.

1967b). Moisture competition is greater between fescue and ponderosa pine than between muhly and ponderosa pine (Pearson 1942).

Studies of bottlebrush squirreltail in a transplant garden at the lower edge of the ponderosa pine zone suggest considerable inherent differences in phenology. Collections from sites only 17 miles apart, growing under uniform conditions in the transplant garden, differed in average flowering dates by 44 days. Based on the phenologic responses of the various collections and on Hopkins Bioclimatic Law, it is estimated that native bottlebrush squirreltail will begin flowering, on the average, in early June at the bottom edge of the ponderosa pine type and in mid-July to early August in the middle and upper portions of the type. This particular pattern of blooming is the result of an interaction of hereditary adaptation, seasonal distribution of precipitation, and growing season length (Clary 1972).

Flowering dates for some of the forbs in the pine type are given in table 1.

Table 1.--Average initial flowering dates for some of the more abundant forbs on Wild Bill Range and Beaver Creek watershed

	1971		1972	
	Wild Bill	Beaver Creek	Wild Bill	Beaver Creek
Aster, showy	--	Sept. 27	--	Sept. 19
Bahia, ragleaf	Sept. 13	Sept. 13	Sept. 6	Sept. 6
Bluets, Wrights	July 6	June 21	June 27	June 27
Bundleflower, James	--	Aug. 30	--	--
Dandelion, common	April 24	April 12	April 4	March 22
Eriogonum, redroot	--	Aug. 30	--	Aug. 22
Eriogonum, sulfur	--	July 19	--	June 27
Fleabane *(Erigeron formosissimus)*	July 6	July 6	July 24	July 24
Fleabane *(E. schiedeanus)*	Sept. 16	--	Sept. 18	--
Fleabane, spreading	Aug. 16	June 7	June 27	June 27
Fleabane, trailing	May 24	May 10	May 16	May 16
Geranium, Fremont	July 19	July 19	July 24	July 11
Gilia, woody	--	Aug. 30	--	July 11
Goats-beard	July 6	July 6	June 27	June 27
Goldenrod, Missouri	Aug. 30	Aug. 2	Sept. 6	Aug. 22
Indigobush, white	--	June 21	--	--
Knotweed, prostrate	July 19	July 19	July 11	July 11
Lettuce, prickly	Sept. 13	Aug. 16	Sept. 6	Aug. 22
Milkvetch	June 21	April 12	June 12	April 18
Mullein, flannel	Aug. 16	Aug. 16	Aug. 6	Aug. 22
Pea, red-and-yellow	June 21	June 21	June 12	June 13
Phlox	--	May 10	--	March 22
Pussytoes, Rocky Mountain	June 7	June 7	May 31	May 16
Sagebrush, flat	Aug. 30	Sept. 13	Sept. 6	Sept. 6
Sweetclover, yellow	June 21	June 21	--	June 13
Thistle, Wheeler	Aug. 16	Aug. 16	July 24	Aug. 6
White-ragweed	--	June 7	--	June 27
Willowweed, autumn	--	June 7	--	--
Yarrow, western	Aug. 16	Aug. 16	July 24	July 24

Herbage Production

The total production of understory herbaceous plants in the ponderosa pine type varies with weather, soils, management history, and timber overstory density. The typical ponderosa pine stand in the Southwest has only 60 square feet of pine basal area per acre, perhaps 5 square feet of other tree basal area, and, depending upon the site, perhaps a few shrubs. Such an open stand allows 200 to 300 pounds per acre of herbaceous plants to be produced. Some areas have several times this density of trees, however, and produce little herbage.

Production values under Beaver Creek watershed (Brown et al. 1974) cutover stands, where basal areas per acre average 92 square feet for ponderosa pine, 18 for Gambel oak, and 5 for alligator juniper, are:

Species	**Production** (*Pounds per acre*)
Grasses and grasslike plants	
Bluegrass, mutton	23
Dropseed, black	10
Grama, blue	23
Sedge	6
Squirreltail, bottlebrush	46
Others	16
Forbs and half-shrubs	
Aster, showy	3
Fleabane, spreading	4
Fleabane, trailing	3
Goldeneye, showy	3
Ragweed, western	7
Sagebrush, flat	3
Snakeweed, broom	3
Others	32
Shrubs	
Locust, New-Mexican	3
Oak, Gambel	13
Total	198

On the Wild Bill range (Pearson 1964), typical unthinned forest stands averaged 120 square feet of basal area per acre of ponderosa pine. There were no other tree species present. Understory production on untreated areas averaged:

Species	**Production** (*Pounds per acre*)
Grasses and grasslike plants	
Dropseed, pine	3
Fescue, Arizona	32
Muhly, mountain	44
Sedge	11
Squirreltail, bottlebrush	10
Others	2
Forbs and half-shrubs	
Fleabane	2
Lupine	5
Others	10
Shrubs	
Ceanothus, Fendler	T
Total	119

Effect of overstory.—It is generally understood that, as forest density increases, the productivity of the herbaceous understory decreases. This inverse relationship has generally been shown to be curvilinear (Pearson 1964, Jameson 1967, Clary 1969), although Cooper (1960b) and Arnold (1950) reported linear relationships. The herbage yields on productive sites vary from 50 to 75 pounds per acre under dense timber (fig. 10) to 1,000 to 1,200 pounds per acre on moderately grazed open grasslands. Open grasslands and forest openings that have had little or no grazing may have yields of 1,400 pounds per acre (Arnold 1955). Yields of herbage from the less productive soils, however, may be only half of those described above (Arnold 1950, Clary et al. 1966).

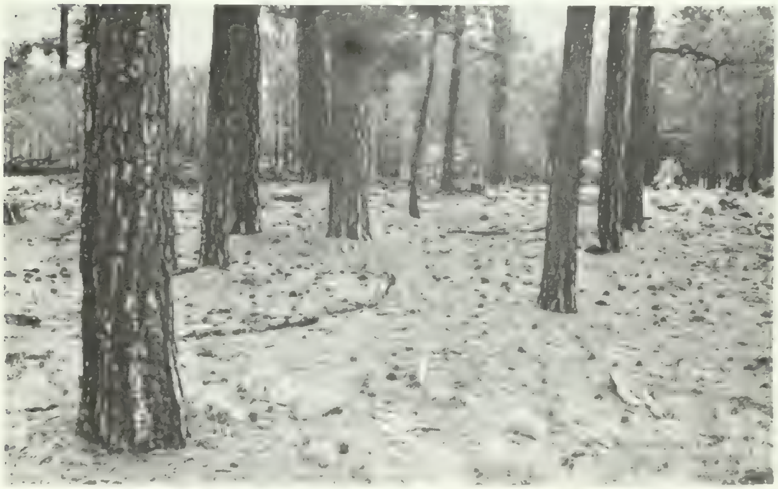


Figure 10.—Little herbage is produced under dense ponderosa pine stands.

The impact of this herbage-timber relationship (fig. 11) has been strongly felt by range managers. The establishment and subsequent development of the prodigious 1919 seedling crop of ponderosa pine across much of northern Arizona has resulted in a continuous decline in herbage production independent of grazing effects (Arnold 1950).

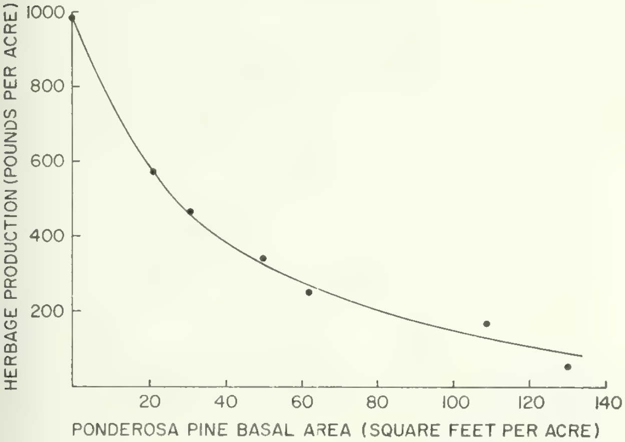


Figure 11.—Relation of herbage production to timber basal area on the Wild Bill range.

The relationship of herbage production to timber density is affected by timber management. Six years after thinning a ponderosa pine stand on the Beaver Creek watershed, herbage production under thinned stands was significantly greater than under unthinned stands for given timber basal areas of less than 70 square feet per acre (fig. 12). Similar results have been found on the Wild Bill range north of Flagstaff (Pearson 1967a). These thinning studies have indicated a rapid response of herbaceous vegetation to overstory reduction, although Arnold (1953) reports response may not always occur, particularly when the vegetation is suppressed by thick slash or heavy grazing. Reynolds (1962a) found the herbage production peaked about 6 years after logging, and suggested that production on selectively logged areas will exceed that of unlogged areas for 11 to 15 years.

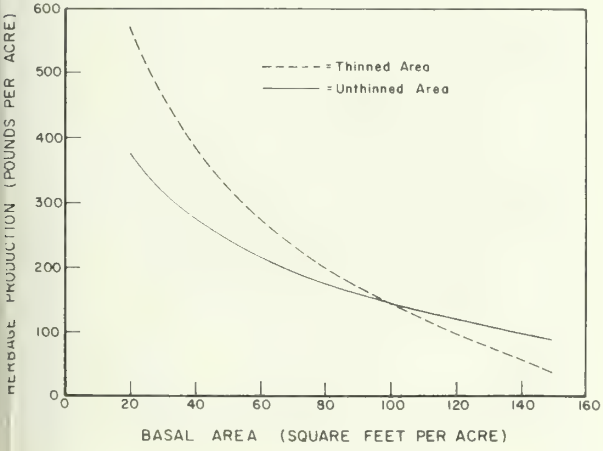


Figure 12.—Relationship between herbage production and timber basal area on thinned and unthinned areas (after Clary and Ffolliott 1966).

Effect of soils and weather.—In timber stands above 40 to 60 square feet of basal area, the production of herbage is similar on all soils, if the soils are developed from volcanic parent materials. However, where timber does not dominate the site, as in timber stands of very low density or in forest openings, large differences in herbage yields on different soils are possible (Arnold 1950, Clary et al. 1966). The more permeable of the volcanic-derived soils that produce the best timber are also capable of producing the most herbage.

Ffolliott and Clary (1975) show that understory-overstory relationships can differ under both high and low timber densities when soils differ greatly in parent material (volcanic versus sedimentary).

Little work has been completed concerning the effect of weather on herbage yields. A preliminary study has suggested a near linear increase in yields with increases in precipitation (Ffolliott and Clary 1974). Further work is needed however because, similar to the response to soils, the largest herbage response to annual weather differences will logically be where timber overstory dominance is minimum.

Effect of fire.—The proper place of fire in the southwestern ponderosa pine type has been the subject of considerable discussion. Pearson (1927) felt that the presence of fire-caused forest openings has resulted in timber production of half of the potential in some areas. Conversely, Weaver (1951) and Cooper (1960a) felt that periodic fires are a natural constituent of the southwestern ponderosa pine type, and have been important in developing and maintaining the "normal" stand structure of the type. They suggest that fire suppression, and to some extent overgrazing, have resulted in a timber stand structure dominated by young pine thickets. This change has reduced long-term timber and forage production.

We still need to learn much about the actual impact of fire on different forest values in the southwestern ponderosa pine type. Gaines et al. (1958) suggested that grass densities had recovered by the second year after a September controlled burn, but not after an October burn. Studies of the forest floor (Clary et al. 1968, Davis et al. 1968) suggest that fires must be sufficiently intense to modify the lower or H layer of the forest floor before herbage production will increase meaningfully.

A severe fire on the Wild Bill range crowned in a dense stand of ponderosa pines and essentially eliminated the trees (Pearson et al. 1972). On an area thinned to 20 square feet basal area per acre, however, the fire remained on the ground and tree density was not significantly reduced. Herbage production increased as much as 1,000 pounds per acre where fire had killed the timber stand. Increases were small in the ground fire area.

Factors Influencing Livestock Production

Improving Forage Production

Range condition.—Results from the Beaver Creek watershed and the Wild Bill range suggest that herbage yields may be roughly similar for similar undisturbed sites even though plant composition varies. Thus, if nonforage species are present, less of the forage species will be produced.

When a range is in good condition, the floristic composition is relatively consistent throughout the stand, so production of palatable grasses will increase with decreasing timber density (fig. 13). However, if livestock have grazed forest openings excessively, range condition will be poor, and floristic composition will be variable. Much of the herbage production in the openings will consist of unpalatable species, and the few remaining bunchgrasses will likely be "hiding" in the dense timber (fig. 14).

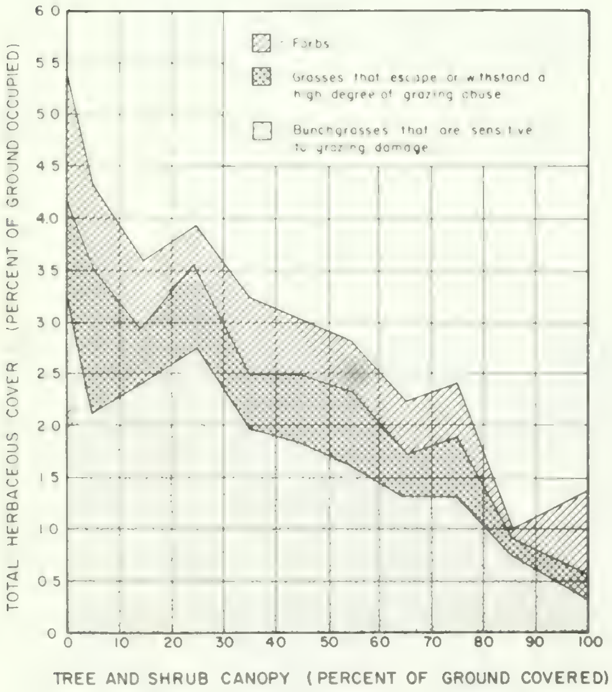


Figure 13.—The relationship between ungrazed herbaceous plant cover (in exclosures) and canopy classes of uneven-aged forest stands (after Arnold 1950).

Herbage production by **forage** plants differs greatly under different range condition classes (table 2). One major way of improving forage yields is to improve management so that the range condition trend is upward.

Control of undesirable plants.—Unpalatable and poisonous species are often directly removed from the range to allow more forage to grow. Minimal work has been done in Arizona on control of unwanted plants in the ponderosa pine type.

Colorado rubberweed, or pingue, is often a problem in the ponderosa pine type, both because of displacement of forage plants and because it is poisonous to sheep. This species can be controlled by 2 to 4 pounds per acre of an ester of 2,4-D or TBA (Johnsen 1962). The herbicides are apparently most effective when applied during rapid plant growth in the prebud stage, preferably when the soil is moist.

Broom snakeweed, often a pest plant in the ponderosa pine type, reduces grazing capacity and may cause poisoning loss. Early work on controlling this species was done in more arid vegetation types (Parker 1939b). Parker found that grubbing, mowing, burning (with a flame gun), and chlorate sprays were effective controls. Similar methods were suggested for other undesirable plants (Parker 1939a).

Applications of 2,4-D and 2,4,5-T reduced the production of broom snakeweed and Cooper actinea

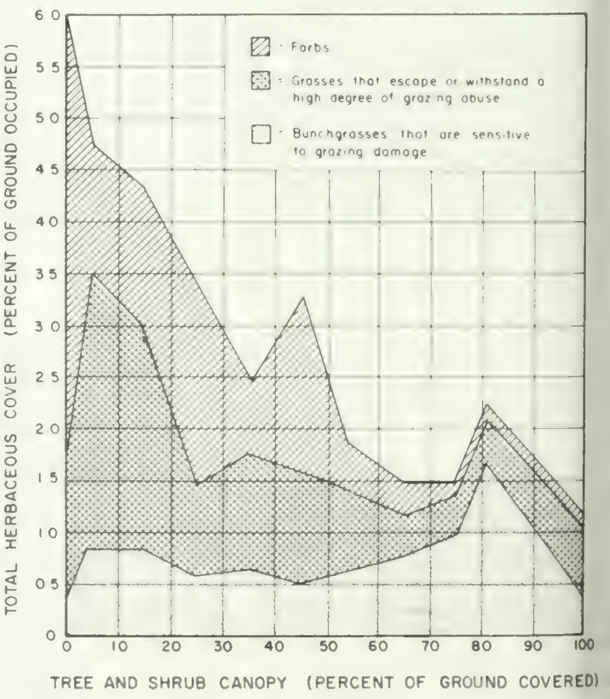


Figure 14.—The relationship between grazed herbaceous plant cover and canopy classes of uneven-aged stands (after Arnold 1950).

Table 2.--Relationships between cover and herbage yields of forage plants related to range condition classes (after Arnold 1955)

	Cover (percent of basal line intercept)			
Type and condition	Bunchgrasses	Other herbaceous plants	Total	Mean air-dry herbage yields of forage plants
		Percent		*Lb/acre*
Mountain meadows				
Excellent	10.59	2.87	13.46	6,351
Good	7.15	3.50	10.66	4,116
Fair	4.04	4.88	8.92	2,850
Poor	1.19	6.56	7.75	1,692
Very Poor	.02	6.64	6.66	1,374
Abandoned cropland	0	10.70	10.70	(1/)
Pine-bunchgrass openings				
Excellent	8.17	1.34	9.51	1,452
Good	5.45	2.53	7.98	988
Fair	2.48	6.25	8.73	699
Poor	1.35	7.77	9.12	518
Abandoned cropland	.02	2.52	2.54	(1/)

1/ Not sampled because areas were grazed at the time of observation.

by 90 and 60 percent, respectively, in north-central Arizona (Jameson 1966).

Gambel oak typically occurs in tree form in Arizona, and is not considered to be a significant range problem. However, control of the shrub form of Gambel oak may be required in some areas because: it can reduce forage yields, it can be a physical barrier to livestock movement, and it can cause livestock poisoning. On the Beaver Creek watershed, ammonium sulfamate crystals placed in trunk frills or girdles killed the tree crowns, but the base of the trees and the roots sprouted profusely. Dormant-season basal applications of 12 pounds per hundred gallons, acid equivalent, of an ester of 2,4,5-T in diesel oil killed many plants and repressed sprouts. Pelleted fenuron treatments also reduced sprouts (Johnsen et al. 1969).

Information from various sources on control of undesirable plants has been consolidated in the Nonstructural Range Improvements Handbook (USDA-FS 1970a) and the Guide to Improvement of Arizona Rangeland (Arizona Interagency Range Technical Sub-Committee 1973).

Because of changing regulations concerning pesticide use, current local, State, and Federal regulations should be checked before using chemicals to control undesirable plants.

Seeding.—Range seeding, properly done, can help mprove forage production on many lands. Among he worthwhile reasons for reseeding are: to restore perennial grasses on ranges where they are now so scarce that natural recovery will take too long; to correct seasonal deficiencies in green forage; to provide special-use areas needed in a sound ranch management plan; and to prevent erosion where there is danger of soil loss (Reynolds et al. 1949).

Natural parks or openings, varying from 10 to 100 acres, are common throughout the ponderosa pine type. Many of them have been so disturbed by overgrazing or farming, that few perennial forage plants remain. These openings, along with areas disturbed by logging or fire, are good candidates for reseeding efforts.

The essential steps for successful reseeding are: (1) select productive sites, (2) remove competing vegetation, (3) plant suitable species, (4) use good seed, (5) observe proper rate and depth of planting, and (6) plant at the proper season (Reynolds et al. 1949).

When seeding deteriorated openings, return on investment will probably be greatest on level or gently sloping sites with fertile soil and good moisture conditions. Species seeded must not only be well adapted to the environment in which they are expected to grow, but they also must be suited to the purpose for which they are needed. Table 3 provides a good choice of species for meeting various requirements. These were the best adapted species out of over 170 that were tested under various conditions. Crested wheatgrass and intermediate wheatgrass have generally shown the widest range of adaptability, although once established, big bluegrass can produce outstanding yields (Lavin and Springfield 1955). In areas with annual precipitation above 25 inches, orchardgrass, smooth brome, and tall oatgrass may produce a more palatable and nutritious forage (Reynolds et al. 1949).

The selection of species to be seeded should be based in part upon the period when they will be grazed. Livestock tend to prefer the species that are most succulent during the grazing period. For instance, orchardgrass, smooth brome, and slender wheatgrass are preferred over big bluegrass and the wheatgrasses for early fall grazing (Lavin and Springfield 1955).

Removal of competitive vegetation before seeding is essential for good results. Disk-type plows have generally proved best for preparing sites. They effectively remove competing vegetation without loosening the seedbed excessively. For best results the seed should be drilled rather than broadcast, unless the seedbed is well prepared.

Recommended seeding rates vary according to species from less than 1 pound to about 15 pounds per acre, but generally average 6 to 10 pounds of good quality seed. For the southwestern ponderosa pine zone, plantings made from about mid-June to mid-July, just prior to or at the beginning of the summer rains, have been most consistently successful (Lavin and Springfield 1955, USDA-FS 1970a).

Establishment of a grass stand is often necessary to retard erosion on recent burns and other timber lands disturbed by logging and other activities. Under these conditions there is usually a suitable seedbed and little competing vegetation, therefore broadcast seeding can be effective as well as economical. Drilling may be required on compacted areas such as logging roads.

On logging roads used intermittently and on drainageways, long-lived sod-forming grasses such as intermediate wheatgrass and smooth brome will give maximum protection. Where quick, but temporary, erosion control is needed until young pines become established, short-lived grasses (table 3), sweetclover, and annual mustards should be considered (Lavin and Springfield 1955).

New plantings need protection for at least the first two growing seasons so that the plants can develop enough root system and top growth to withstand grazing. Thereafter, the seeding should be grazed conservatively so forage production can be maintained.

Seeding is only one of the ways to improve rangelands. The possibilities of improving native range through better management should be carefully considered before attempting costly seeding work. Careful management is required to maintain forage production regardless of whether an area is seeded.

Additional detailed information on planting techniques and adapted species is available in two handbooks: Nonstructural Range Improvements Handbook (USDA-FS 1970a) and Guide to Improvement of Arizona Rangeland (Arizona Interagency Range Technical Sub-Committee 1973).

Table 3.--Relative success ratings of 23 species tested at 5 locations in ponderosa pine openings (after Lavin and Springfield 1955)

Species	Location and elevation (ft)				
	Jarita Mesa (8300)	Fort Valley (7400)	White Horse Lake (6900)	Peterson Flat (6500)	No Agua (8200)
	- - - Relative success[1] - - -				
LONG-LIVED GRASSES:					
Bluegrass, big	E	G	F	0	NT
Brome, smooth	G	G	G	F	NT
Orchardgrass	F	F	G	0	NT
Wheatgrasses--					
Beardless	G	G	F	F	F
Bluebunch	E	G	0	VP	NT
Western	F	E	E	G	NT
Crested	G	E	G	G	E
Intermediate	E	E	E	F	E
Pubescent	E	G	G	P	G
Tall	G	G	G	F	F
Wildrye, Russian	G	E	G	F	NT
SHORT-LIVED GRASSES:					
Brome, California	G	G	G	F	NT
Oatgrass, tall	G	G	G	F	NT
Rye--					
Mountain	E	E	G	G	NT
Winter	G	G	E	F	NT
Timothy	F	P	F	0	NT
Wheatgrass, slender	E	E	E	G	E
Wildrye--					
Blue	E	G	F	VP	NT
Canada	F	E	F	VP	NT
LEGUMES:					
Alfalfa--					
Grimm	F	F	G	P	NT
Ladak	F	F	[illegible]	F	NT
Sweetclover (biennial)--					
White	E	P	G	F	NT
Yellow	G	P	F	F	NT

[1] Relative success: E=Excellent; G=Good; F=Fair; P=Poor; VP= Very Poor; 0=Failure; NT=Not Tested.

Other techniques.—Forage yields can also be improved by fertilization and water spreading. There apparently has been little documentation of the effectiveness of these techniques in the Arizona ponderosa pine type.

A single fall fertilization of intermediate wheatgrass with nitrogen increased herbage production for 4 years (Lavin 1967). Over the 4-year period, nitrogen levels of 33, 66, and 99 pounds per acre produced 31, 35, and 27 pounds of dry matter per pound of nitrogen, respectively. Phosphorus fertilization had little effect on plant growth.

An indirect benefit of fertilizing is that cattle distribution can be manipulated because of the attraction of the animals to fertilized areas. Investments in fertilization should be approached carefully, however, as it is often questionable whether the increase in animal weight gain will be sufficient to justify the cost (Duvall 1970).

Nutritional Value of Forage Plants

Much of the nutritional information applicable to Arizona ponderosa pine ranges has been developed at the Wild Bill range (Pearson 1964). Chemical constituents and digestibility of typical forages on ponderosa pine summer range have been related to timber overstory, season, species, and plant part.

Chemical constituents.—Chemical components of four forage species growing under various pine densities were analyzed to determine the effects of tree overstory (table 4). Crude protein content was higher in forages growing in the open than under a timber overstory. This trend was not apparent for phosphorus and ash content. Some differences in crude protein were apparent among species; crude protein content was greatest in bottlebrush squirreltail and least in mountain muhly.

Table 4.--Some chemical constituents of four forage species in the open and under a timber overstory[1] (Lines connect species that are not significantly different. Plants were significantly higher in crude protein in the open than under a tree cover.)

Constituent and overstory condition	Mountain Muhly	Arizona fescue	Dryland sedge	Bottlebrush squirreltail
	percent			
Crude protein				
Open	6.8	10.6	11.7	16.0
Timbered	6.1	7.5	9.5	9.7
Phosphorus				
Open	.20	.30	.22	.25
Timbered	.18	.24	.18	.26
Ash				
Open	8.4	10.2	10.6	12.3
Timbered	8.0	11.6	9.8	13.7

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[1] Pearson, H. A. Personal communication.

Similar studies showed average seasonlong nutri-ional values did not differ greatly among heads, stems, and leaves of a plant.

Forage diet mixtures, as determined by paired plot echniques, showed a constant decline in crude protein content through the summer (from 12.5 percent in late June to 6.5 percent in late September). No seasonal trend in mineral content was apparent.

Digestibility.—The value of a forage species to a herbivore is largely related to its digestibility. In vitro orage digestibility studies (Pearson 1970) show that orages grown in the open are significantly more digestible than those grown under a timber overstory, although the differences are not large:

	Open	**Timbered**
	(Percent digestibility)	
Mountain muhly	50.9	47.6
Arizona fescue	57.4	51.6
Dryland sedge	58.6	54.6
Bottlebrush squirreltail	66.7	61.0

Heads and stems generally increased in digestibility from August to September, while leaves decreased. On the average, leaves were more digestible than stems and heads in August, and heads were more digestible in September (Pearson 1967c). When the herbage of two grass species was clipped and segregated into upper, middle, and lower segments (Pearson 1964), the herbage from the lower portions of the plants was less digestible.

Since cattle are selective grazers, the stage of plant development and nutritive value of plant parts will probably influence animal preference (Pearson 1967c). Livestock selectivity is demonstrated in some 1965 data. Digestibilities of composite cattle diets, as determined from paired plots, averaged 61.9, 54.1, and 51.4 percent for the periods June 19, August 10 to 13, and September 15 to 27, respectively. However, digestibilities of Arizona fescue and mountain muhly, the primary forage species present, averaged only 59.2, 46.5, and 44.5 percent for the same periods.

Effect of fire.—The effects of wildfire on subsequent forage quality are summarized in table 5. Crude protein, phosphorus, and in vitro digestibility were higher in the forages from the burned area the first growing season. Increases in digestibility and phosphorus content lasted through the second growing season.

Table 5.--Nutrient content of native forages on burned (B) and unburned (U) areas (after Pearson et al. 1972)

Date	In vitro digestibility		Crude protein		Phosphorus	
	B	U	B	U	B	U
	Percent					
1967:						
June	63.4	62.5	16.3	12.0	0.43	0.23
August	65.6	57.2	18.6	12.1	.39	.32
October	68.7	59.9	9.6	7.9	.27	.23
1968:						
July	65.2	62.0	9.2	10.0	.25	.22
August	61.1	53.6	9.5	9.8	.22	.21
September	51.3	50.1	9.6	9.6	.27	.22
1969:						
July	56.5	56.3	--	--	--	--

Livestock nutrition.—Nutritional levels of the typical summer range diet in Arizona ponderosa pine are generally adequate for yearlings (Halls 1970, Shepherd and Hughes 1970). Crude protein content does drop below required levels in late September, however. Seasonal intake of digestible protein and digestible energy also appears adequate (Howard 1971).

While ponderosa pine-bunchgrass forage meets minimum requirements for reasonable animal production, it does not necessarily produce optimum animal gains. The possibility certainly exists for increased animal production in some areas through intensive management of pastures seeded to species of higher average nutritional levels, or to species that maintain adequate nutritional levels for a longer period of the year (Malechek 1966).

The only livestock supplement that appears to be needed on ponderosa pine summer range is salt. However, on those few allotments that are grazed yearlong or in winter only, protein and possibly phosphorus supplements may be needed to maintain adequate nutritional levels (Shepherd and Hughes 1970).

Deer nutrition.—Chemical analyses and in vitro digestibilities were made to determine the plants and plant parts important in the summer diet of deer in north-central Arizona (table 6). The nutritional quality of these summer diets appears to be quite good. Although a considerable variety of plants was available each month from May to September, Gambel oak leaves were rather consistently the predominant forage component in the summer diet.

Although few direct comparisons are possible, it appears that the diet selected by deer (the particular species and plant parts) may have higher nutritional value than the primary forage species consumed by cattle.

Table 6.--Chemical analyses and in vitro digestibility for some forage species consumed by deer[1]

Plant	Crude protein	Calcium	Phosphorus	In vitro digestibility
		-percent-		
Grasses				
Bluegrass	14	0.40	0.28	54
Bottlebrush squirreltail	12	.25	.30	52
Orchardgrass	19	.31	.38	60
Forbs				
Clover	28	.94	.42	70
Common dandelion	13	1.14	.41	54
Fleabane	10	1.04	.23	60
Geranium	10	1.08	.31	58
James bundleflower	15	1.07	.19	45
Peavine	24	1.17	.29	64
Red-and-yellow pea	15	1.32	.24	40
Redroot eriogonum	13	.77	.29	39
Slender milkvetch	20	.69	.25	70
Sweetclover vetch	24	.83	.36	63
Yellow sweetclover	21	1.28	.20	66
Browse				
Fendler ceanothus	18	.80	.26	52
Gambel oak	15	.58	.27	48
Ponderosa pine	7	.19	.14	41

[1] Urness, P. J., and J. R. Vahle, Rocky Mountain Forest and Range Experiment Station, and D. J. Neff, Arizona Game and Fish Department, personal communication.

Grazing Patterns and Forage Preferences

Grazing patterns.—Poor animal distribution may greatly reduce long-term animal production, and is a major contributor to range deterioration. Concentration of animals in the more productive forage sites often results in the decline or ultimate destruction of forage plants. Also, if the animals rarely graze the more inaccessible portions of the range, a portion of the animal production potential is never realized.

Ponderosa pine naturally grows in groups with scattered forest openings and open parks. The bunchgrass ranges are therefore often characterized by extremely uneven forage utilization (Glendening 1944). Grazing is normally most intense in forest openings or where the trees are scattered. Under heavy stocking, these openings can be grazed so severely that the bunchgrasses are completely eradicated, even though they reach their greatest abundance in the openings if protected from grazing. Conditions may decline to the point that the only bunchgrasses exist as isolated "islands" under dense timber (Arnold 1950). This condition of extreme overuse in the openings and underuse in the timber typifies many ponderosa pine ranges.

A number of factors influence the manner in which pine-bunchgrass ranges are grazed, when reasonably stocked with cattle. These include:

1. Distance from water (fig. 15).
2. Steepness and length of slope (fig. 16).
3. Trails and other access routes. These are important where timber or other natural barriers restrict animal movement.
4. Density of the timber stand. Utilization decreases as the forest density increases. Livestock seem to be attracted to forest openings and/or repelled by dense timber stands.

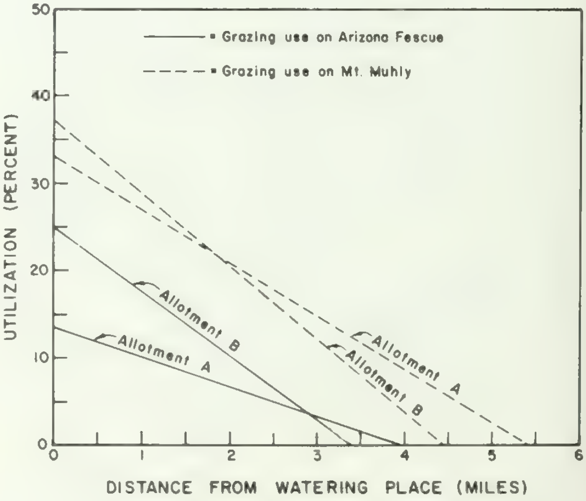

Figure 15.—Decrease in grazing use due to distance from water (after Glendening 1944).

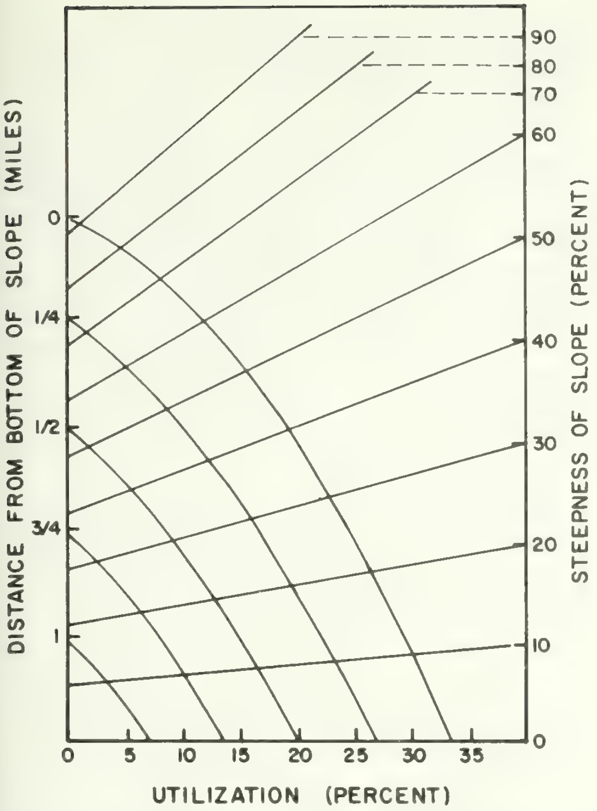

Figure 16.—Effect of steepness and distance from bottom of slope on percent grazing use of mountain muhly (after Glendening 1944).

5. Floristic composition and season of use. Arizona fescue is grazed most heavily in early summer, but the remainder of a summer growing season mountain muhly receives the heavier use. Grazing use of Arizona fescue decreases with increased abundance of mountain muhly.
6. Range condition. Ranges in poor condition, whether caused by overgrazing (usually more accessible), or fire or mechanical damage (remaining plants are often more succulent), tend to be closely grazed year after year, so that improvement in plant cover is prevented (Glendening 1944).

Forage preferences.—Glendening (1944) referred to the effect of floristic or plant composition on the response by grazing animals. A study of relative cattle preference for various forage species in northern Arizona (Clary and Pearson 1969) showed Kentucky bluegrass, Arizona fescue, and mountain muhly were most preferred under summer-long grazing, while blue grama and prairie Junegrass were least preferred. The following preferences are utilization percentages when associated bottlebrush squirreltail was grazed 20 percent:

Species	Preference (*Percent utilization*)
Kentucky bluegrass	39
Arizona fescue	33
Mountain muhly	31
Black dropseed	28
Sedge	24
Mutton bluegrass	23
Bottlebrush squirreltail	20
Blue grama	17
Prairie Junegrass	13

Because cattle spend more time grazing where forage is more abundant, species that tend to occur in areas of greatest accessibility may tend to be more prominent in the diet. This appears to be the case at the Wild Bill range. A diet preference rating was calculated as the ratio—Percent of species in diet:Percent of species in floristic composition. Ratios for pine dropseed, mutton bluegrass, bottlebrush squirreltail, and dryland sedge all indicated greater relative use than Arizona fescue and mountain muhly.

In a study of cattle preference for seeded grasses, orchardgrass, smooth brome, and slender wheatgrass were most preferred; crested wheatgrass, Kentucky bluegrass, and tall oatgrass were intermediate in preference; while western wheatgrass and big bluegrass were least preferred (Springfield and Reynolds 1951).

Animal preferences vary among forage species during a grazing season. The animals usually exhibit the greatest preference for a given species when it is growing rapidly, and when its succulence and digestibility are high (Springfield and Reynolds 1951, Pearson 1967c).

Range Condition, Grazing Systems, and Degree of Use

Range condition.—Range condition is a measure of the health of the range, based on what that range is naturally capable of producing. Range condition classes are a series of arbitrary categories used to classify range condition, which is usually expressed as either excellent, good, fair, or poor. Range condition trend is the direction of change in range and soil condition (Am. Soc. Range Manage. 1964).

Numerous systems have been developed for detecting range condition and trend. The 3-step method was adopted by the USDA Forest Service in 1956 (Parker and Harris 1959). Later studies determined, however, that accurate trend interpretation from conventional 3-step data is much more difficult and complex than originally hoped (Reppert and Francis 1973). In addition, loop-frequency has little consistent relationship to plant cover, herbage production, or plant density (Francis et al. 1972). Thus, although the 3-step system with its range condition scorecards is still in use, the hoped-for simultaneous attributes of simplicity and maximum usable information are yet to be achieved. The Southwestern Region of the Forest Service has modified the 3-step method to include additional information on plant composition (USDA-FS 1970c). This modification provides a stronger data base, although it does not change the basic system.

The guidelines given by Arnold (1950) provide a good general direction for judging range condition, particularly as it is affected by grazing:

A. Do not confuse the reduction of forage production by thickening of the timber stand with that caused by improper livestock management. Increasing timber density has little effect upon the herbaceous floristic composition, but grazing does.
B. Unsatisfactory range condition is indicated by:
    1. A scarcity of bunchgrasses (Arizona fescue, mountain muhly, screwleaf muhly, and mutton bluegrass).
    2. A replacement of bunchgrasses with perennial grasses that escape or withstand a high degree of grazing abuse (blue grama, bottlebrush squirreltail, black dropseed, Fendler threeawn, and Arizona threeawn).
    3. A marked replacement of all perennial grass species by perennial forbs.
    4. An abundance of annuals.
    5. The survival of remnant bunchgrass "islands" under scattered trees. (See also earlier section on Successional Pattern.)

Ranges in top condition are desirable not only from an ecological standpoint, but also from a practical standpoint. Ranges in good to excellent condition can be expected to produce several times more palatable forage than does a range in poor condition (Arnold 1955).

Grazing systems.—The value of specialized grazing systems has recently been reviewed by Driscoll (1967), Shiflet and Heady (1971), Hickey (n.d.), and Martin and Cable (1974). The results of applying specialized (usually some type of rotation) grazing systems vary greatly from case to case. Sometimes the forage crop is benefited, sometimes the livestock, sometimes both, and sometimes neither. While specialized grazing systems are usually somewhat beneficial, they also have some drawbacks. Some advantages of rotational grazing systems are that they:

1. Provide periodic deferment or rest to allow desirable forage species to regain vigor.
2. Provide more complete use of the forage resource through better livestock distribution. Livestock also exhibit less plant selectivity within and between forage species.
3. Allow for the integration of seeding and control of undesirable species into the grazing plan without additional fencing for grazing control.

The primary disadvantages are the expense, mainly the development of additional livestock water and fencing, and in some cases depressed livestock gains. Gains may be less if cattle must eat less nutritious forage during some parts of the season, or are disturbed by frequent moving (Driscoll 1967).

No one system is best for all conditions; the system used should be tailored to each particular situation. The optimum system may even differ on the same grazing allotment as range condition changes. Major points to consider in selecting a grazing system for a particular allotment include:

- Kind and class of animal to be grazed.
- Kind and amount of vegetation.
- Amount and seasonal occurrence of rainfall.
- Topography and elevation.
- Length of growing season.
- Kind and characteristics of soil.
- Range condition and trend.
- Availability of funds for fencing, water development, and other range improvements.
- The needs of the livestock operator.

Grazing systems generally used on USDA Forest Service allotments in Arizona ponderosa pine include:

- Continuous.
- Rotation (two to four or more units).
- Deferred.
- Rest-rotation.
- Deferred-rotation.

Documented results are lacking as to which, if any, of the specialized grazing systems will produce optimum results. Systems recommended for semidesert grass-shrub ranges (Martin and Cable 1974) may not be directly applicable in the ponderosa pine type. Experienced range managers in Region 3 of the USDA Forest Service believe, however, that definite benefits have accrued on forested ranges from rest-rotation and deferred rotation systems under proper stocking. Pearson et al. (1971) reported a successful three-pasture rest-rotation system implemented in the Arizona ponderosa pine type. The system was designed to fit cool- and warm-season species growing in response to Arizona's distinct summer and winter precipitation periods. Documentation of plant and animal response was minimal, however.

Rotational grazing systems are probably the most effective in improving range condition when (1) site differences within range units are large and distribution is a problem, and (2) major forage species differ greatly in growth timing, life-form, or palatability.

The first requirements of any system of grazing, however, are proper use of the forage crop and uniform distribution of the grazing animals (Shiflet and Heady 1971).

Degree of use.—Little, if any, recent work has been documented on the proper amount of grazing use for the forage species on Arizona ponderosa pine ranges. Crafts (1937) suggested these utilization standards to alleviate livestock browsing on pine reproduction:

	Utilization	**Minimum leaf stubble height**
	(Percent)	*(Inches)*
End of spring drought (July)		Within 1½ inches of ungrazed areas
Arizona fescue	15	
Mountain muhly	10-15	
End of season (Oct.)		
Arizona fescue	35-40	6
Mountain muhly	45	4

Later guides were a bit more conservative (table 7).

Table 7.--Utilization standards for forage species on Arizona ponderosa pine ranges (from Parker 1942)

Species	Normal range		Steep slopes or deteriorated ranges	
	Stubble height	Volume removed	Stubble height	Volume removed
	Inches	*Percent*	*Inches*	*Percent*
Arizona fescue	6.0	25	8.5	15
Black dropseed	--	40	--	25
Bottlebrush squirreltail	4.0	40	5.0	30
Kentucky bluegrass	1.5	50	--	40
Mountain muhly	4.0	30	8.0	15
Pine dropseed	2.5	50	3.5	30
Prairie Junegrass	2.0	40	3.0	30

The "proper use factor" of 30 to 40 percent, often used on USDA Forest Service allotments, appears to be about right, although no definitive studies have been made.

Grazed-class photo guides (Schmutz 1971) and grazed-plant methods (Springfield and Peterson 1964) are useful in estimating the degree of utilization for several major forage species. Production-utilization methods now employed on the Southwestern National Forests (USDA-FS 1970c) use ocular estimates and mapping techniques. These methods provide weighted utilization means and mapped utilization distribution, which are quite useful in allotment management.

Beef Gains

Related to nutrient consumption.—Consumption of nutritious forage makes animal production possible. One of the best methods of assessing range value is by estimating potential animal gains based on forage intake and digestibility (Pearson 1972). Since forages can differ in nutritive value from year to year on various ranges, the digestibility measurements enhance forage evaluations. Forages from different ranges can then be compared, regardless of species composition.

A relationship has been developed that provides predictions of beef yields per acre for yearling heifers grazing southwestern ponderosa pine summer range (fig. 17). Information on consumption can be combined with data on digestibility to provide estimates of livestock production potential. This relationship was developed under conditions in which average utilization generally did not exceed 40 percent.

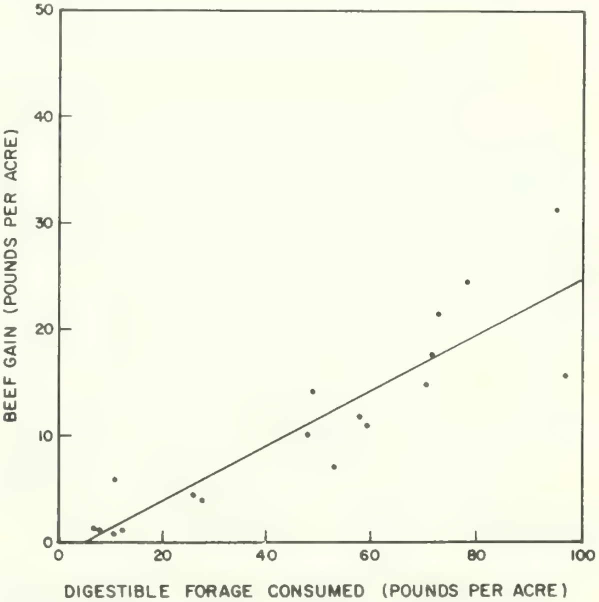

Figure 17.—Relationship between digestible forage consumed and beef gain per acre (after Pearson 1972).

An equation based on total dry matter consumption, instead of digestible dry matter consumption, was slightly less effective as a predictor of beef gains, but requires less data. The equation is: $G = 0.141C - 0.643$; where G = pounds of gain per acre, and C = pounds of dry matter consumed per acre (Pearson 1972).

The effect of forage digestibility on animal performance was demonstrated near Flagstaff, Arizona. Two groups of yearling steers from the same herd were grazed on ponderosa pine summer ranges about 30 miles apart and at about 500 feet difference in elevation. Digestibility of the diet components from the south range was 64.1 percent, while from the north range the average was 53.2 percent. Cattle gains were estimated to be 1.84 and 1.51 pounds per day, respectively, based on the assumption of similar forage intake on the south and north ranges (Henry

A. Pearson, formerly with Rocky Mountain Forest and Range Experiment Station, personal communication). These estimates compare favorably with actual gains of 1.92 and 1.45 pounds per day, and illustrate the differences in animal performance that can be expected due to forage digestibility.

A larger variety of forage species apparently provides more choice for the grazing animals, and they can select more nutritious diets.

Related to timber density.—Animal production per acre is greatly increased by reductions in the timber overstory, primarily through an increase in the forage supply. Other benefits include improved livestock distribution and perhaps a slight increase in forage quality. The relationship between tree density and beef gains per acre has been determined on the Wild Bill range with data from 1965 to 1971. These data were developed from range units thinned to various levels of tree density and grazed over a 4-month season at levels generally not exceeding 40 percent use. The relationship of beef gain to timber basal area (fig. 18) closely follows that of herbage yield to timber basal area. This indicates that, when livestock are well distributed, potential animal production increases roughly in proportion to an increase in forage supply. The maximum indicated potential beef gain is about 30 to 35 pounds per acre per year with complete timber overstory removal. Livestock production approaches zero under high-density ponderosa pine stands.

Physical relationships between beef and wood production and 1972 unit prices suggest that the combined economic value of grazing and saw-log production would be maximum in tree stands having a basal area of about 45 to 60 square feet per acre (Clary et al. 1975).

Related to use.—Animal performance on the Wild Bill range was affected by grazing intensity. Average daily gain per animal declined as percent utilization increased:

Utilization (*Percent*)	**Daily Gain** (*Pounds*)
≤ 25	1.42
26-50	1.28
≥ 51	1.12

Management of Livestock to Avoid Losses from Poisonous Plants

Nearly all poisonous plants are unpalatable, and cattle eat them only when forced by hunger or when mineral deficiencies result in depraved appetites. Animals normally vary their diet, and with adequate forage will seldom consume hazardous amounts of any one species of poisonous plant. Also, the presence of vigorous forage plants tends to inhibit the invasion and growth of poisonous plants. Thus good range management is the most practical and effective means of reducing long-term livestock losses due to poisoning on rangelands. Management techniques useful in reducing short-term poisoning losses include:

1. Feed mineral supplements (especially salt and phosphorus) to alleviate depraved appetites.
2. Use supplemental feed if the forage supply is short during critical periods.
3. Choose a season when the plants are less toxic or when toxic plants are less palatable.
4. Change to a kind of livestock that is less susceptible to the particular plant poison.
5. Keep livestock away from poisonous plant concentrations by riding, herding, salting, or fencing (Parker 1939c).

Poisonous plants in the Arizona ponderosa pine type, as taken from Schmutz et al. (1968), are:

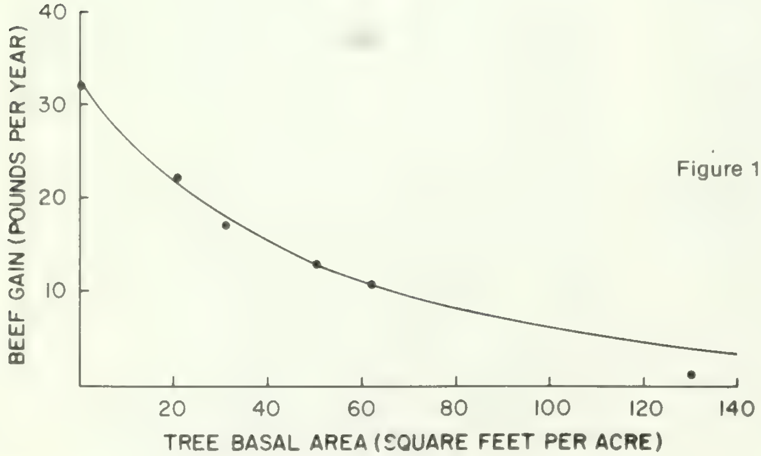

Figure 18.—Relationship of beef gain to tree basal area (after Clary et al. 1975).

Major poisonous plants

Cocklebur
Douglas water-hemlock
Larkspur
Locoweed
Mountainmahogany (?)
Paperflower
Pingue
Russianthistle
Snakeweed
Threadleaf groundsel
Whorled milkweed

Secondary poisonous plants

Annual goldeneye
Bracken
Chokecherry
Cloakfern
Coulter conyza
Cutleaf nightshade
Deathcamas
Ergot
False-hellebore
Filaree
Gambel oak
Golden corydalis
Gray horsebrush
Horsetail
Lupine
Ponderosa pine
Sacred datura
Spreading dogbane
(Indian hemp)
Spurge
Tansy-mustard
Western monkshood
Western sneezeweed

Grazing History, Current Conditions, and Allotment Needs

Stocking Rates and Carrying Capacities

Grazing use of the Arizona ponderosa pine type, and indeed all of the western ranges (Dutton 1953), has varied considerably over the past 100 years. Livestock numbers and degree of use were quite high from the late 1800's until the end of World War I (Seltzer and Pfuehler 1959). Thereafter, stock numbers declined as range abuse became widely recognized (fig. 19).

On those Arizona National Forest allotments that are 75 percent or more in the ponderosa pine type, approximately 15,000 permitted cattle (fig. 20) are grazed for a total of 80,000 animal-unit months (AUM) (based on 1973 allotment data from Region 3, USDA-FS). There were no sheep or dual use permits among the allotments meeting the 75 percent criteria.

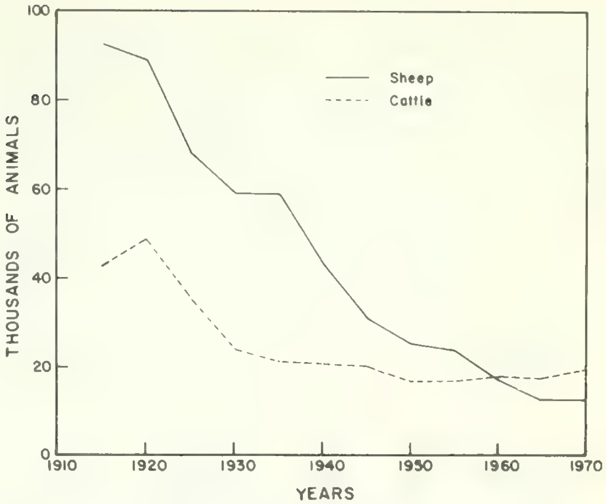

Figure 19.—Numbers of cattle and sheep grazed on the Coconino National Forest.

Potential carrying capacities of Arizona ponderosa pine rangelands have been estimated at 5 to 8 acres per AUM (Cooper 1959, Reynolds 1962b, Pase 1966). Actual grazing capacities vary considerably, generally in direct proportion to the forage supply. Production of herbaceous plants is strongly influenced by woody overstory, soils, and weather. Plant composition, vigor, and other factors that combine to describe "range condition" also greatly affect grazing capacities.

The average estimated grazing capacities and distribution of Arizona ponderosa pine ranges on National Forest land, by condition class, are:

Condition class	**Grazing capacity** *(Acres/AUM)*	**Distribution** *(Percent)*
Excellent	insufficient data	1
Good	7	6
Fair	10	48
Poor	18	40
Very poor	41+	5

Figure 20.—Beef cattle are the major domestic livestock.

These differences illustrate the tremendous impact of range condition on grazing capacities, especially when we consider that 45 percent of the ponderosa pine rangeland is in unsatisfactory condition (USDA-FS 1973).

The average estimated proper stocking rates for the different National Forests in Arizona are:

	(Acres AUM)
Apache-Sitgreaves	12.0
Coconino	10.3
Kaibab	12.0
Tonto	31.5

Season of Grazing

A large portion of the Arizona ponderosa pine is grazed in summer only. Generally, this vegetation type is not suited to yearlong or winter use because of cold temperatures and deep snow. Acreages grazed in summer only average 87 percent for the Apache-Sitgreaves and Coconino National Forests, which have the largest ponderosa pine acreages of the Arizona Forests. The yearlong allotments tend to be in the more southern portion of the ponderosa pine type. Across the State the averages for the ponderosa pine type are:

	(Percent)
Yearlong	16
Summer only (generally May 1-Oct. 31)	79
Winter only (generally Nov. 1-Apr. 30)	3
Not indicated	2

Grazing Systems

In the early days, continuous grazing by excessive numbers of livestock, often coupled with poor distribution, resulted in many areas being totally "grazed out." Often, little recovery is evident 50 years later.

Considerable progress has been made in water developments, fencing, and so forth, to improve animal distribution. Various kinds of grazing systems have been applied to National Forest allotments.

The distribution of acreage, under broad classes of grazing systems, is:

	(Percent)
Continuous	9
Rotation	15
Deferred	19
Rest-rotation	42
Deferred-rotation	11
Not indicated	4

Thus, a high proportion of the ponderosa pine allotment acreage is currently under some type of an improved grazing system.

The existence of an "improved" grazing system on paper will accomplish nothing unless it is conscientiously applied on the ground. Even those so applied need to be examined periodically and modifications made if needed.

Some Immediate Allotment Needs

Even though the use of improved grazing systems is widespread on the National Forests, and even though livestock numbers are considerably below the numbers of the earlier, abusive years, only 55 percent of the ponderosa pine allotment acreage is in satisfactory condition. Obviously, considerable additional range improvement needs to be done.

"The first requirement of any so-called system of grazing . . . is still proper use of the forage crop and the uniform distribution of the grazing animals" (Shiflet and Heady 1971). An allotment needs first of all to be stocked commensurate with the forage supply available. In 1973, Arizona ponderosa pine ranges were being subjected to 35 percent more AUMs of grazing than was estimated to be proper (based on data from Region 3, USDA-FS). Carrying capacity estimates will likely change of course, as other changes are made in grazing management.

Uniform distribution of grazing animals is another important major requirement. When common range management practices are coordinated so as to complement each other, many grazing distribution problems are alleviated or prevented (Driscoll 1967). These practices include salting, supplying water, fencing, trail construction, and range riding or herding. While little or no work has been done in Arizona ponderosa pine to quantify the effects of these practices, experiences by livestock producers and public land managers have verified their benefits, especially the development of stock watering facilities. Pearson et al. (1969) described a trick tank design which provides a water supply more cheaply than hauling for those areas where other types of water supplies are not available.

Specialized grazing systems (usually some combination of rotation and deferment) also help alleviate the distribution problem. The cross fencing usually needed with specialized systems provides more control over the animals, and higher animal densities over shorter periods of time cause the livestock to graze less accessible portions of the range unit which they would not otherwise graze. They also graze more of the less palatable species and are less selective in grazing individual plants of the same species. The major advantage of a specialized system, especially if it includes deferment or rest, is that it allows preferred forage plants to recover on those areas which tend to be repeatedly or continuously grazed.

Costs and Returns

Range Improvement Practices and Grazing Intensity

There is very little substantial data concerning costs and returns of livestock operations specifically applicable to Arizona ponderosa pine ranges. Information from various areas will be utilized here in an attempt to develop an idea of economics involved in range livestock operations.

A recent study in the chaparral type of Arizona suggests that the marginal value of an additional AUM of grazing capacity (in 1972) is $5.82, or $70 per animal unit per year (O'Connell and Boster 1974). This animal unit has a current capitalized value of $1,000 at 7 percent interest (Water Resource Council 1973). Thus, to be economically feasible, the cost of a range improvement practice which adds one AU of grazing capacity should not exceed $1,000 total for both the initial improvement and all discounted maintenance expenses. Some typical expenses for the ponderosa pine type in general (Duran and Kaiser 1972) are given in table 8.

In the case of range fertilization, if we use Lavin's (1967) results of a 4-year response to fertilization which resulted in about a 2,300-pound-per-acre cumulative increase in forage production, the value of the increased carrying capacity, even without discounting, may be worth little more than two-thirds of the initial $12 per acre expense.

$$\text{Value} = \frac{(2{,}300\text{ lb.})\ (50\%\text{ use})\ (\$5.82)}{750\text{ lb. intake/AUM}} = \$8.92$$

Assume in the case of seeding, that the practice is applied to a totally depleted area with no current grazing capacity. Lavin and Springfield (1955) suggest a carrying capacity of 3 acres per AUM from successful seedings. Since **successful** seedings require seedbed preparation, the initial investment would be $60 per AUM of increased carrying capacity (3 acres x $20 per acre) (Duran and Kaiser 1972). Assuming the new stand is protected from grazing for 2 years and maintains maximum production for the next 28 years, the present value of the stream of benefits from the increased carrying capacity is also approximately $60. Thus, from a beef production standpoint, the cost of seeding will at best be just returned with little real profit.

Each potential range improvement practice needs to be carefully evaluated in each management situation. Many improvement practice-management situation combinations are not economically feasible from the standpoint of beef production alone. Other considerations, however, may justify such practices (USDA-FS 1970b, Smith and Martin 1972).

The grazing intensity that brings the greatest net revenue varies somewhat from situation to situation. Results from Colorado ponderosa pine ranges (Johnson 1953, Smith 1967) suggest that grazing at 30 to 40 percent utilization provides the greatest net revenue. Returns from Arizona semiarid grasslands were greater when they were grazed at 40 to 50 percent utilization than at 70 to 80 percent (Ariz. Inter-Agency Range Comm. 1972).

An equation has been developed (Pearson 1973) for estimating the degree of forage utilization that will

Table 8.--Some costs and expected life of range management practices in the ponderosa pine type of western United States (Duran and Kaiser 1972)

Management practice	Unit	Labor		Equipment and material	Total costs	Expected life of practices[1]
		Skilled	Unskilled			
						(years)
Fertilization	Acre	$ 1.00	$ --	$ 11.00	$	[2]1
Brush control:	Acre					
Mechanical		3.50	1.00	10.50	15.00	8
Chemical		1.00	.25	4.75	6.00	8
Fire		1.00	5.50	1.50	8.00	8
Debris disposal	Acre	2.00	3.50	2.50	8.00	30
Undesirable forb control	Acre	2.00	--	9.00	11.00	15
Mechanical soil treatments	Acre	3.00	.50	8.50	12.00	25
Seeding	Acre	1.50	.50	6.00	8.00	30
Prescribed burn	Acre	.75	3.50	1.25	5.50	5
Rodent control	Acre	.50	--	3.00	3.50	30
Insect and disease control	Acre	.50	--	1.00	1.50	20
Water developments:	Each					
Small		175.00	75.00	350.00	600.00	25
Large		300.00	650.00	850.00	1,800.00	30
Fences	Mile	300.00	1,000.00	700.00	2,000.00	30
Timber thinning	Acre	21.00	1.50	2.50	25.00	30

[1] Time until need reappears.

[2] Response lasted 4 years in Lavin's (1967) study.

yield maximum profit. Factors included are cost per animal day, revenue per pound of beef, gain per animal day, digestible forage consumed per acre, and digestible forage consumed per animal-day. Several of these are computed from forage production and forage digestibility. For the typical examples given, the grazing use to maximize net profit on Arizona ponderosa pine ranges would be 30 to 38 percent. Apparently it is financially unwise to graze such ranges at greater than 40 percent because costs are likely to increase faster than gross returns.

Economics of Cattle Ranching

The economics of cattle ranching apparently follow similar patterns in many of the vegetation types. The size of the ranch operation and carrying capacity of the land both strongly affect the cost efficiency of producing beef (Boykin et al. 1966). Projected total costs for ranches producing more than 4,000 hundredweight of beef annually and having a 30 animal unit (AU) per section carrying capacity are only one-third as much per hundredweight as for ranches producing less than 200 to 300 hundredweight of beef annually and having a carrying capacity of 6 AU per section (Martin and Goss 1963).

If beef production is considered as the only ranch output, and real estate appreciation is ignored, returns to management are negative for all sizes and types of operations if capital is charged at its opportunity cost (Martin and Goss 1963). Computed net returns to capital and management vary from negative on small ranches to 1 or 2 percent on larger ranches, based on market prices of commercial ranches in Arizona. Regardless of the mix of public and private lands contained in the ranch operation, market prices are well above a rational value based on the capitalized value of the ranch's earning potential (Smith and Martin 1972). Because of economies of scale in cattle ranching, however, the marginal value product of an additional block of land may be considerably higher than the average value product of the whole ranch. Most ranches are much smaller than the size where long-run costs become constant (Martin 1966).

The capitalized value of an additional animal unit of grazing capacity to established ranches is currently $1,000 (O'Connell and Boster 1974). In other words, although it is not economically rational to purchase an entire ranch at prices approaching $1,000 per AU, it may be worthwhile to add to an existing ranch unit at these prices to improve economies of scale, or to spend equivalent sums to increase grazing capacity on existing lands.

Correlating Grazing with Other Uses

Water

The effects of grazing on water yield and quality are important, since the ponderosa pine type is the source of nearly half of the streamflow in the Salt River watershed in Arizona (Cooper 1959).

Brown et al. (1974) studied the effect of grazing on water yields. A watershed previously converted from ponderosa pine to a grass cover was grazed spring and fall, with the intent of removing 50 percent of the standing crop of perennial grasses during each grazing period. The 50 percent goal was not attained in several instances, but the total annual use on perennial grasses averaged nearly 60 percent for the period of the study. The grazing treatment has not increased water yield. This result can reasonably be applied to other ponderosa pine ranges in Arizona on heavy-textured volcanic soils.

Further tests are necessary to evaluate the impact of grazing on runoff from sedimentary soils, since grazing has affected runoff under some other conditions (Dunford 1949, Rauzi and Hanson 1966) and not under others (Rich and Reynolds 1963). The effects on erosion and sediment movement are likewise variable (Dunford 1949, Rich and Reynolds 1963) although, in general, erosion due to grazing has not been a major problem in the timbered areas of Arizona (USDA-FS 1936).

Timber

The primary negative impact of grazing on timber production is the potential damage to regeneration. Pearson (1927) suggested that grazing was the reason forest openings protected from fire failed to regenerate. There is considerable evidence that severe overstocking of livestock in the early days of forest grazing in the West did damage young timber reproduction. Apparently, sheep caused more damage than cattle. This damage was eventually recognized, and grazing guides were developed to reduce the damage.

It was suggested, but not proved, that thirst is an important factor causing sheep and cattle to browse pine seedlings, especially in the dry Arizona springtime (Cassidy 1936, 1937). If so, this damage can be alleviated by changing management and distribution of livestock water so that the trailing distance between water and green feed is reduced. It was also suggested that utilization rates be limited to 10 to 15 percent of the principal forage species during the spring drought so that plenty of forage is available (Crafts 1937).

Often, intensive silvicultural management can benefit production of both timber and forage. Thinning to increase the production of marketable timber

Schubert 1971) will often increase forage production o long as thinning slash is not too dense.

Some authors feel that fire suppression policies ave resulted in thickets of pine regeneration that ave reduced the production of marketable timber nd forage, and have changed the nature of the onderosa pine forests (Weaver 1951, Humphrey 959, Cooper 1960a). They conclude that both timber nd forage production would benefit by allowing atural fires to burn. Pearson (1927), on the other and, considered fire an enemy of maximum ponerosa pine timber yields.

Most reports on the effects of fire suppression olicies and prescribed burning appear to be observaional. The impact of low-intensity wildfires and rescribed burns on overall timber production has et to be documented. While growth on crop trees nay increase after fire, particularly in thinned areas, he net effect on many stands may be negative Lindenmuth 1960, Pearson et al. 1972). The overall ffects on forage plants are to (1) increase nutritional uality of plant growth, and (2) increase total erbage production as a result of thinning the timber tands.

Vildlife

Although the effect of livestock grazing on wildlife as not been specifically studied in the Arizona onderosa pine type, an adequate forage supply is bviously important to big-game animals (Reynolds 969, Clary and Larson 1971). Forage yields are ighest in parks and forest openings, which are referred by cattle and elk, and if the areas are not oo large, by deer as well (Reynolds 1962c, 1969). This mutual preference by large herbivores creates he potential for competition. Results from the eaver Creek watershed indicate that intensive livestock grazing can cause both deer (fig. 21) and elk to avoid an area (Neff 1972). The presence of some slash may tend to favor deer over cattle and therefore reduce direct competition (Reynolds 1966a, 1966b). Observations that light to moderate grazing by livestock seem to have little noticeable effect on big-game animals correspond with results from other areas (Julander 1962, Skovlin et al. 1968), although elk are probably more affected by cattle competition than are deer.

Reductions of the timber overstory, whether done primarily to improve yields of water, timber, or herbage, will virtually always increase herbage. Big-game usually respond to this improved forage supply if cover is not limiting (Neff 1972). While slash cleanup may be detrimental to deer use (Reynolds 1966a, Pearson 1968), other practices such as seeding exotic grasses may benefit elk. Seeding following wildfire improves the habitat for both elk and deer (Kruse 1972).

Little information appears to be available on most other wildlife species. Overgrazing is detrimental to turkey populations (fig. 22), but the degree of harm has not been documented (Lewis 1973). Some competition apparently occurs between livestock and pocket gophers (Turner et al. 1973), and considerable competition may occur between livestock and other rodents, such as prairie dogs (Taylor 1930). Studies on various grassland areas show that smaller wildlife species can be indirectly affected by grazing if the grazing influences the plant successional stage.

A great void remains in the knowledge of the impact of grazing and other management practices on the biota of an area, although the knowledge gap has been long recognized (Taylor 1927). The broad sponsorship of the recent Symposium on Management of Forest and Range Habitats for Nongame Birds (Smith 1975) indicates an intensifying interest in public management responsibility for wildlife species in addition to those traditionally supported by hunter interests.

igure 21.—Deer are widespread throughout the Arizona ponderosa pine ranges.

Figure 22.—The Merriam's turkey is relatively common on many of the Arizona ponderosa pine ranges.

Emerging Resource Demands and Research Needs

Emerging Demands

Southwestern rangelands are becoming increasingly more important for values other than the production of domestic livestock. Open space, natural beauty, recreation, water, clean air, and wildlife are increasingly recognized as important rangeland values, particularly by the urban dweller.

In a similar vein, the public is becoming aware of and concerned about the management of public lands. Satisfaction of society's demands appears in large part to hinge on the maintenance of environmental quality. Fortunately, good range management is in harmony with environmental quality, and should deliver near-maximum returns to the livestock operator (Sampson 1952). In addition, **quality** range management does not appear to conflict with other forest uses and values, such as timber production, water quality and quantity, wildlife, and esthetics and recreation. A philosophical orientation toward environmental quality rather than maximum livestock production may seem financially disastrous at first, but the maintenance of a quality range does result in near-optimum long-term livestock production.

Although animal production can be increased through improved range condition and grazing management, it appears unlikely that ranch returns can be improved to the point that ranches are a rational economic investment at the marketplace under economic conditions similar to the 1960's through the mid-1970's. Without counting on continued real property appreciation, monies invested in livestock ranches for the past several years have far exceeded their ability to produce beef and income. Values other than revenue production have been strong motives in ranch ownership for some time (Smith and Martin 1972).

More information is needed for the ponderosa pine type concerning investment and returns for entire ranch operations and for specific management activities and improvements. In addition, information is needed on social and economic values of rangeland uses other than production of domestic livestock.

Some Additional Research Needs

A thorough knowledge of any ecosystem is necessary to appropriately apply management techniques. As part of that knowledge, rangelands need to be characterized and classified to provide a basis for the development and implementation of effective programs and policies. The Forest-Range Environmental Study (USDA-FS 1972a) has pointed out that efficient production of beef on western ranges in the future will require more intensive management on productive sites, and the elimination of grazing on unproductive or poor sites. These areas need to be identified. Extension of the habitat-typing work proposed by Region 3 of the USDA Forest Service[3] appears to be a good start on the problem.

Multiple use management, often complicated, is essential to maintaining both environmental quality and the economic base for rural communities. Manipulation of vegetation to increase livestock carrying capacity by such practices as timber harvesting, type conversion, selective plant control, and the introduction of new plant species can greatly influence such characteristics as habitat quality, landscape and recreational value, and water quality. The impacts of management practices on many forest uses and values are not well enough understood to provide a knowledge base suitable for consistently making the best management decision.

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[3] *Chambers, John W. 1973. A prospectus for cooperative effort to classify habitat types in Region 3. (Unpublished report on file at office of Regional Forester, R-3, USDA-FS, Albuquerque, N.M.)*

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Common and Botanical Names of Plants Mentioned

Grasses and Grasslike Plants

Common Name	Botanical Name[4]
Bluegrass	*Poa* spp.
Bluegrass, big	*P. ampla*
Bluegrass, Kentucky	*P. pratensis*
Bluegrass, mutton	*P. fendleriana*
Bluestem, little	*Andropogon scoparius*
Brome, California	*Bromus carinatus*
Brome, mountain	*B. marginatus*
Brome, smooth	*B. inermis*
Deergrass	*Muhlenbergia rigens*
Dropseed, annual	*Sporobolus* spp.
Dropseed, black	*S. interruptus*
Dropseed, pine	*Blepharoneuron tricholepis*
Fescue, Arizona	*Festuca arizonica*
Grama, blue	*Bouteloua gracilis*
Junegrass, prairie	*Koeleria cristata*
Muhly, mountain	*Muhlenbergia montana*
Muhly, screwleaf	*M. virescens*
Muhly, spike	*M. wrightii*
Oatgrass, tall	*Arrhenatherum elatius*
Orchardgrass	*Dactylis glomerata*
Rye, mountain	*Secale montanum*
Rye, winter	*S. cereale*
Sedge	*Carex* spp.
Sedge, dryland	*C. geophila*
Squirreltail, bottlebrush	*Sitanion hystrix*
Threeawn, Arizona	*Aristida arizonica*
Threeawn, Fendler	*A. fendleriana*
Timothy	*Phleum pratense*
Wheatgrass, beardless	*Agropyron inerme*
Wheatgrass, bluebunch	*A. spicatum*
Wheatgrass, crested	*A. desertorum*
Wheatgrass, intermediate	*A. intermedium*
Wheatgrass, pubescent	*A. trichophorum*
Wheatgrass, slender	*A. trachycaulum*
Wheatgrass, tall	*A. elongatum*
Wheatgrass, western	*A. smithii*
Wildrye, blue	*Elymus glaucus*
Wildrye, Canada	*E. canadensis*
Wildrye, Russian	*E. junceus*

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[4] *Botanical names generally follow Kearney, Thomas H., Robert H. Peebles, and collaborators. 1969. Arizona flora. 1085 p. Univ. Calif. Press, Berkeley.*

Forbs and Half-shrubs

Common Name	Botanical Name
Actinea, Cooper	*Hymenoxys cooperi*
Alfalfa, Grimm	*Medicago sativa* hort. var. Grimm
Alfalfa, Ladak	*M. sativa* hort. var. Ladak
Aster, showy	*Aster commutatus*
Bahia, ragleaf	*Bahia dissecta*
Beebalm	*Monarda* spp.
Bluets, Wrights	*Houstonia wrightii*
Bracken	*Pteridium* spp.
Bundleflower, James	*Desmanthus cooleyi*
Cinquefoil	*Potentilla* spp.
Cloakfern	*Notholaena sinuata*
Clover	*Trifolium* spp.
Cocklebur	*Xanthium* spp.
Conyza, Coulter	*Conyza coulteri*
Corydalis, golden	*Corydalis aurea*
Crazyweed, Lambert (or locoweed)	*Oxytropis lambertii*
Dandelion, common	*Taraxacum officinale*
Datura, sacred	*Datura meteloides*
Deathcamas	*Zigadenus paniculatus*
Deervetch	*Lotus* spp.
Dogbane, spreading (or Indian hemp)	*Apocynum* spp.
Ergot	*Claviceps* spp.
Eriogonum, redroot	*Eriogonum racemosum*
Eriogonum, sulfur	*E. cognatum*
False-hellebore	*Veratrum californicum*
Filaree	*Erodium cicutarium*
Fleabane	*E.* spp.
Fleabane	*Erigeron formosissimus*
Fleabane	*E. schiedeanus*
Fleabane, spreading	*E. divergens*
Fleabane, trailing	*E. flagellaris*
Geranium	*Geranium* spp.
Geranium, Fremont	*G. fremontii*
Gilia, woody	*Gilia multiflora*
Globemallow	*Sphaeralcea* spp.
Goats-beard (or salsify)	*Tragopogon dubius*
Golden-pea	*Thermopsis* spp.
Goldeneye, annual	*Viguiera annua*
Goldeneye, showy	*V. multiflora*
Goldenrod	*Solidago* spp.
Goldenrod, Missouri	*S. missouriensis*
Groundsel	*Senecio* spp.
Groundsel, threadleaf	*S. longilobus*
Horsetail	*Equisetum arvense*
Hymenoxys (or Actinea)	*Hymenoxys* spp.
Indigobush, white	*Dalea albiflora*
Iris (or flag)	*Iris* spp.
Knotweed, prostrate	*Polygonum aviculare*
Lambsquarters	*Chenopodium album*
Larkspur	*Delphinium* spp.
Lettuce, prickly	*Lactuca serriola*
Locoweed	Certain *Astragalus* spp. and *Oxytropsis lambertii*
Lupine	*Lupinus* spp.
Meadowrue	*Thalictrum fendleri*
Milkvetch	*Astragalus* spp.

Forbs and Half-shrubs (cont.)

Common Name	**Botanical Name**
Milkvetch	*A. tephrodes*
Milkvetch, slender	*A. recurvus*
Milkweed, whorled	*Asclepias subverticillata*
Mock-pennyroyal	*Hedeoma* spp.
Monkshood, western	*Aconitum columbianum*
Mullein	*Verbascum* spp.
Mullein, flannel	*V. thapsis*
Mustard, annual	*Brassica* spp.
Nightshade, cutleaf	*Solanum triflorum*
Paintbrush	*Castilleja* spp.
Paperflower	*Psilostrophe* spp.
Pea, red-and-yellow	*Lotus wrightii*
Peavine	*Lathyrus* spp.
Penstemon (or beard tongue)	*Penstemon* spp.
Phlox	*Phlox woodhousei*
Pussytoes	*Antennaria* spp.
Pussytoes, Rocky Mountain	*A. aprica*
Ragweed, western	*Ambrosia psilostachya*
Rubberweed, Colorado (or pingue)	*Hymenoxys richardsonii*
Russianthistle	*Salsola kali*
Sagebrush, flat	*Artemisia carruthii*
Sandwort	*Arenaria* spp.
Snakeweed, broom	*Gutierrezia sarothrae*
Sneezeweed, western	*Helenium hoopesii*
Spurge (or euphorbia)	*Euphorbia* spp.
Sweetclover	*Melilotus* spp.
Sweetclover, white	*M. albus*
Sweetclover, yellow	*M. officinalis*
Tansy-mustard	*Descurainia pinnata*
Thistle	*Cirsium* spp.
Thistle, Wheeler	*C. wheeleri*
Toadflax	*Comandra* spp.
Vetch, American	*Vicia americana*
Vetch, sweetclover	*V. pulchella*
Violet	*Viola* spp.
Water-hemlock, Douglas	*Cicuta douglasii*
White-ragweed	*Hymenopappus lugens*
Willowweed, autumn	*Epilobium paniculatum*
Wormwood, Louisiana	*Artemisia ludoviciana*
Yarrow	*Achillea* spp.
Yarrow, western	*A. lanulosa*

Trees and Shrubs

Common Name	Botanical Name
Apache-plume	*Fallugia paradoxa*
Aspen, quaking	*Populus tremuloides*
Boxleaf, myrtle	*Pachystima mysinites*
Ceanothus, Fendler (or buckbrush)	*Ceanothus fendleri*
Cliffrose	*Cowania mexicana*
Chokecherry	*Prunus virginiana*
Currant, wax	*Ribes cereum*
Douglas-fir	*Pseudotsuga menziesii*
Elder, blueberry	*Sambucus coerulea*
Fendlerella	*Fendlerella utahensis*
Fernbush	*Chamaebatiaria millefolium*
Jamesia, cliff	*Jamesia americana*
Juniper	*Juniperus* spp.
Juniper, alligator	*J. deppeana*
Juniper, common	*J. communis*
Horsebrush, gray	*Tetradymia canescens*
Locust, New-Mexican	*Robinia neomexicana*
Mahonia, creeping (or Oregon grape)	*Berberis repens*
Manzanita, greenleaf	*Arctostaphylos patula*
Mockorange, littleleaf	*Philadelphus microphyllus*
Mountainmahogany	*Cercocarpus* spp.
Ninebark, mountain	*Physocarpus monogynus*
Oak, Gambel	*Quercus gambelii*
Pine, ponderosa	*Pinus ponderosa*
Pinyon	*Pinus edulis*
Rabbitbrush, Parry	*Chrysothamnus parryi*
Raspberry, American red	*Rubus strigosus*
Rockspiraea, bush	*Holodiscus dumosus*
Rose	*Rosa* spp.
Sagebrush, big	*Artemisia tridentata*
Sagebrush, black	*A. nova*
Snowberry	*Symphoricarpos* spp.
Sumac, skunkbush	*Rhus trilobata*

Agriculture—CSU, Ft. Collins

Clary, Warren P.
1975. Range management and its ecological basis in the ponderosa pine type of Arizona: The status of our knowledge. USDA For. Serv. Res. Pap. RM-158, 35 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

This paper, intended to serve as a reference for managers of forested ranges, summarizes and evaluates available information about Arizona ponderosa pine-bunchgrass ranges. It covers physical-biological characteristics, factors influencing livestock production, grazing allotment conditions, and economics, and correlates grazing with other uses. Several knowledge gaps are also identified.

Keywords: Range management, grazing systems, pine-bunchgrass range.

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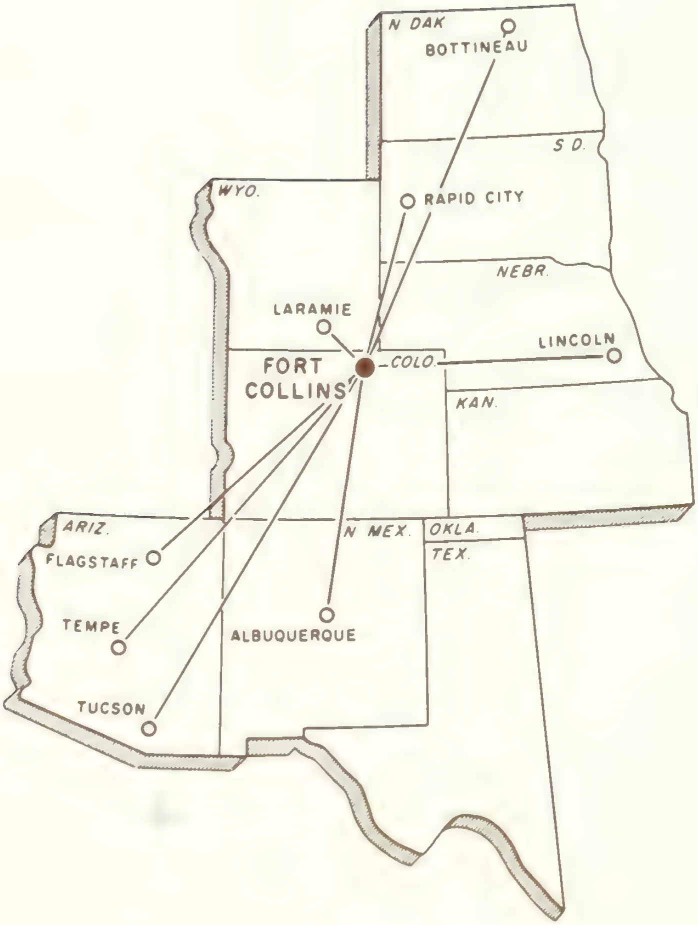
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O. Currie

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Abstract

Currie, Pat O.
1975. Grazing management of ponderosa pine-bunchgrass ranges of the central Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-159, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Pine-bunchgrass ranges have historically been important livestock-producing areas in the central Rocky Mountains. Grazing will continue to be important, but in conjunction with other uses of the land. Livestock-management techniques are well developed and soundly based on research within the pine-bunchgrass type. There is a need, however, to understand the interrelationships of other land uses, particularly as they relate to human population pressures. Research needs, as well as what is known, are described for several vegetation cover types. Other resources, such as timber, soil, and water, are evaluated in relation to grazing.

Keywords: Grazing management, pine-bunchgrass type, *Pinus ponderosa.*

USDA Forest Service
Research Paper RM-159

December 1975

GRAZING MANAGEMENT OF PONDEROSA PINE-BUNCHGRASS RANGES OF THE CENTRAL ROCKY MOUNTAINS:

The Status of Our Knowledge

Pat O. Currie, Principal Range Scientist
Rocky Mountain Forest and Range Experiment Station[1]

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[1] *Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

Contents

Page

Physiographic Features 1
  Geology 3
  Soils 3
  Climatic Characteristics 4
Vegetation 5
Early Grazing Use and Direction for Research 7
Plant and Animal Management on Native Ranges 8
Establishment and Management of Seeded Ranges 12
  Adaptability and Seeding Methods 12
  Grazing Management 14
Cultural Manipulation and Integrated Systems of Management 16
  Cultural Practices 16
  Integrating Native-Seeded Ranges 17
  Additional Practices 18
Factors Affecting the Future of Livestock Grazing and Range Research 19
  Land Use Patterns and Priorities 19
  Relating Demands to Resource Capabilities 20
Literature Cited 21
Common and Scientific Names of Plants and Animals 23

GRAZING MANAGEMENT OF PONDEROSA PINE-BUNCHGRASS RANGES OF THE CENTRAL ROCKY MOUNTAINS:

The Status of Our Knowledge

Pat O. Currie

Historically, ponderosa pine-bunchgrass[2] ranges ave been important livestock-producing areas in the entral Rocky Mountains. Beginning with the disovery of gold in Colorado in 1858, exploitation of the imber resource has been common throughout most of he pine type, and nearly all commercial stands have een harvested one to several times. Harvesting this mber resource altered the vegetation complex by nlarging the natural openings, or creating new ones. omesteaders then established farms and livestock razing operations to feed themselves and the rudientary mining and settlement communities. Thouands of acres were plowed and planted to small rains, hay, and hardy row crops.

The forage resources were heavily utilized by liveock. Hay crops for cattle, horses, and mules were high demand. The cattle industry expanded most pidly between 1880 and 1890. Sheep grazing, owever, did not assume any importance until World ar I, and then only small numbers occupied onderosa pine ranges. By the mid-1930's animal onths of grazing finally began to decline on ational Forest lands. Early reductions came slowly, ut today less than one-third of peak numbers are razing on National Forest lands in Colorado. Simir use patterns developed on the pine lands of New exico and Wyoming. In the whole central Rocky ountain area, long-overdue recognition of the verse effects of mismanagement on watersheds was an important factor responsible for reductions in grazing pressure.

The purpose of this Paper is to bring together what we have learned about grazing these lands, the relationship of this grazing to other uses, and identify the needs for further knowledge.

Physiographic Features

The ponderosa pine-bunchgrass type can best be described as a zone of the central Rockies encompassing about 17 million acres in Wyoming, Colorado, and New Mexico (fig. 1). Only two small islands of the vegetation type occur in Wyoming, along the North Platte drainage. Approximately 10 million acres are in Colorado on both sides of the Continental Divide along watercourses of the South Platte, Arkansas, and Colorado Rivers. The remaining acreages in New Mexico are primarily along drainages of the Rio Grande and Pecos Rivers. The total zone varies from 5 to 25 miles in width and ranges from 5,000 to 9,500 feet in elevation over the 400-mile north-to-south distance. Almost all of the pine-bunchgrass grazing lands of the three States are within this well-defined zone.

Topography of the pine-bunchgrass type is rough and dissected by many tributaries of the major rivers, which often head well above the type. This dissection contributes to a great diversity of landscape aspects (fig. 2) which, combined with the base geology, exerts a profound influence on the vegetation and soils of the type.

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[2] *Common and scientific names of plants and animals entioned are listed at the end of the Paper.*

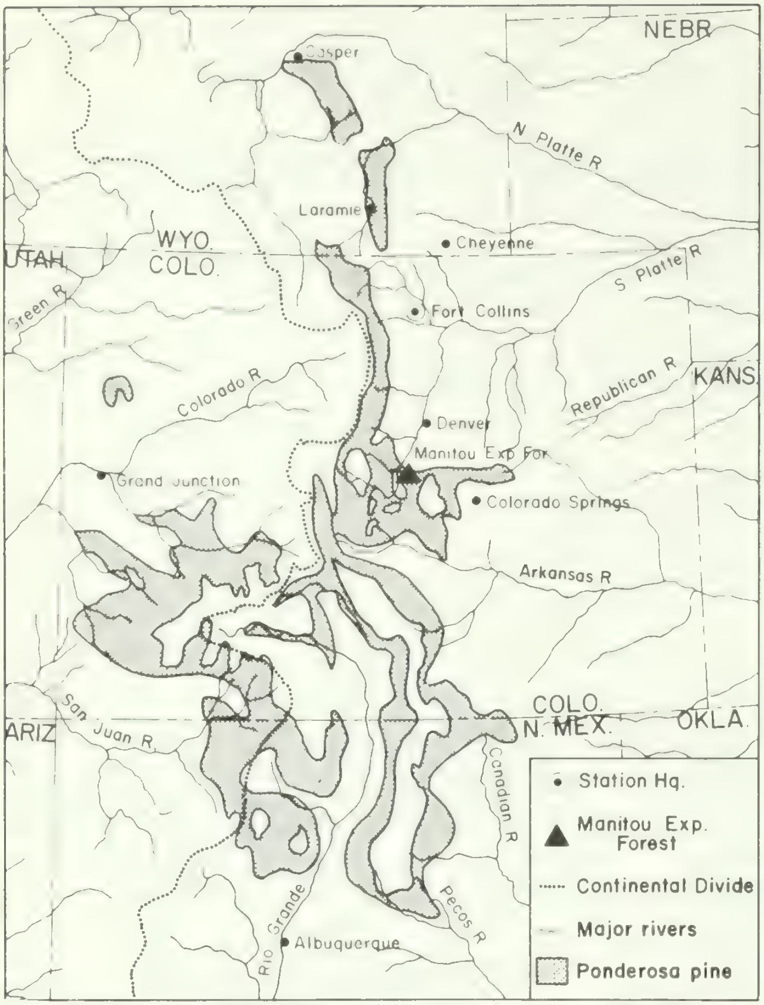


Figure 1.—Distribution of ponderosa pine in the central Rocky Mountains.

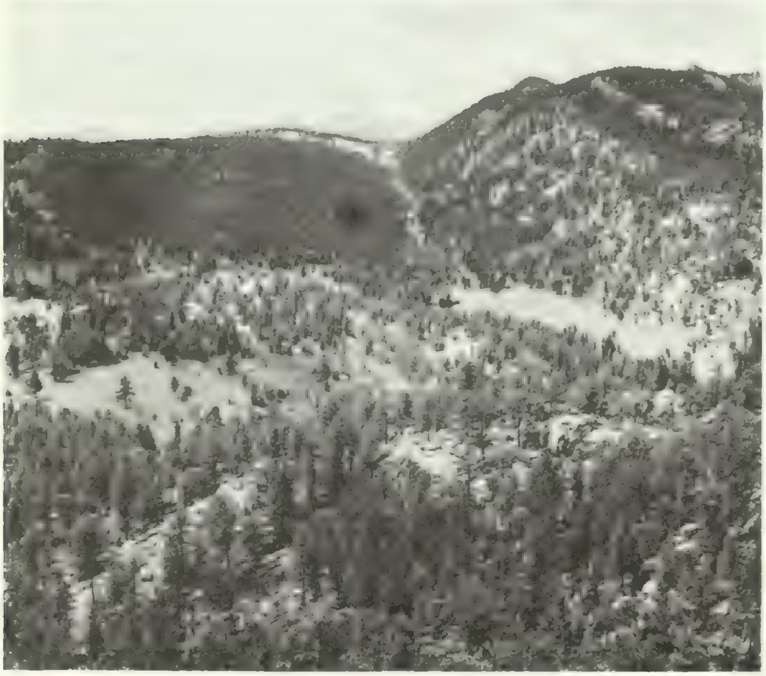


Figure 2.—Dissection of the topography creates a diversity of landscape aspects, which contributes to a mosaic of vegetation patterns.

Geology

The area to the north of the headwaters of the Arkansas River (see fig. 1) has a base geology composed primarily of granites with occasional extrusions of other materials (Marcus 1973). To the south of this imaginary line, base geology is mainly schists, gneiss, and sedimentary sandstones and shales.

Chronic and Chronic (1972), in their guide to the geology of Colorado, divided the State into three scenic provinces: plateaus, mountains, and plains. The ponderosa pine zone is closely associated with their mountain province, which is paralleled and controlled by differences in geologic structure. Prov-nce development, as they describe it, is associated with the class of rock and its origin:

Class and example	**Occurrence in Colorado**
Sedimentary: Sandstone Shale Conglomerate Limestone Extrusive: basalt	Plains, plateaus, flanks of mountain areas
Igneous: Intrusive: granite diorite Marble (from limestone) Quartzite (from sandstone)	Pikes Peak, Longs Peak, and most central mountain areas
Metamorphic: Gneiss (from granite or sandstone) Schist (from shale or basalt)	Mountain areas

oils

The soils developed in different parts of the zone, r from the different classes of rocks, have distinctive haracteristics. Soil depth and morphological devel-pment fluctuate widely with parent materials. In eneral, soils of the pine type have developed from chist, granite, or shale. Only localized areas have oils developed from limestone or sandstone, which re scattered in rather small, restricted areas hroughout the type.

Almost all soils in the type have a high erosion hazard, particularly if the plant cover is depleted or destroyed. Thus protection of the soil is a major oncern in grazing management (Gary 1975).

Of the four common soils, soils derived from granite are the most abundant in the pine type, and may or may not have clay subsoils. Those without a clay layer have a gravelly, sandy loam surface soil, 4 to 8 inches thick, which grades into the parent rock. The parent rock may be weathered and crumbly, or unweathered and massive. Soils on south slopes are drier and contain less surface litter and organic matter than those on north slopes. Where litter or plant cover is absent, the surface is protected by a gravel pavement over a layer of fine-textured material.

Less abundant are granitic soils with clay subsoils. These soils may be residual, or may have developed on old alluvial terraces consisting of granitic materials. Surface soils are 8 to 10 inches thick and are frequently underlain by red clay subsoils that may be 2 or more feet deep. The clay subsoil is compact and well cemented when dry, and lime deposits are occasionally found on small gravels at the base of the subsoil. The granitic parent material is often decomposed, and consists of a reddish brown gravel. A gravel pavement develops where the soil surface is devoid of litter or plant cover. Both of the granitic types of soils are very susceptible to erosion.

Soils developed from schist have a fine, sandy loam surface layer that varies in depth up to 20 inches. Surface soil grades into the parent rock; subsoils are generally absent. The parent rock is often weathered and cracked, which facilitates the movement of water into the substrata. Soils on south aspects are drier than those on the north, and contain less surface litter and organic matter.

Characteristics of soils developed from shales depend upon the aspect and kind of plant cover present. Soils on south aspects are shallow, with surface soils ranging from 6 to 12 inches thick, while those on north aspects or those covered with a dense stand of pine, oak brush, or grass have surface soils 8 to 18 inches thick. Blocklike subsurface soils of varying thickness and predominately clay in texture grade into the parent material. Soils from both aspects are fertile, but are subject to excessive sheet erosion when devoid of an adequate plant cover. Unlike the granitic soils, internal drainage is slow and moisture retention is high.

Associated with the major soils are alluvial soils which develop in valley bottoms and upland pockets formed behind rock outcrops. These alluvial soils are generally deep, and have only surface soils 6 to 18 inches thick. They are brown to dark brown in color, of varying textures, neutral in reaction, and grade into the parent alluvial material which is often loose and porous. These soils have considerable moisture storage capacity, but are easily eroded once gullies start in the valleys.

Climatic Characteristics

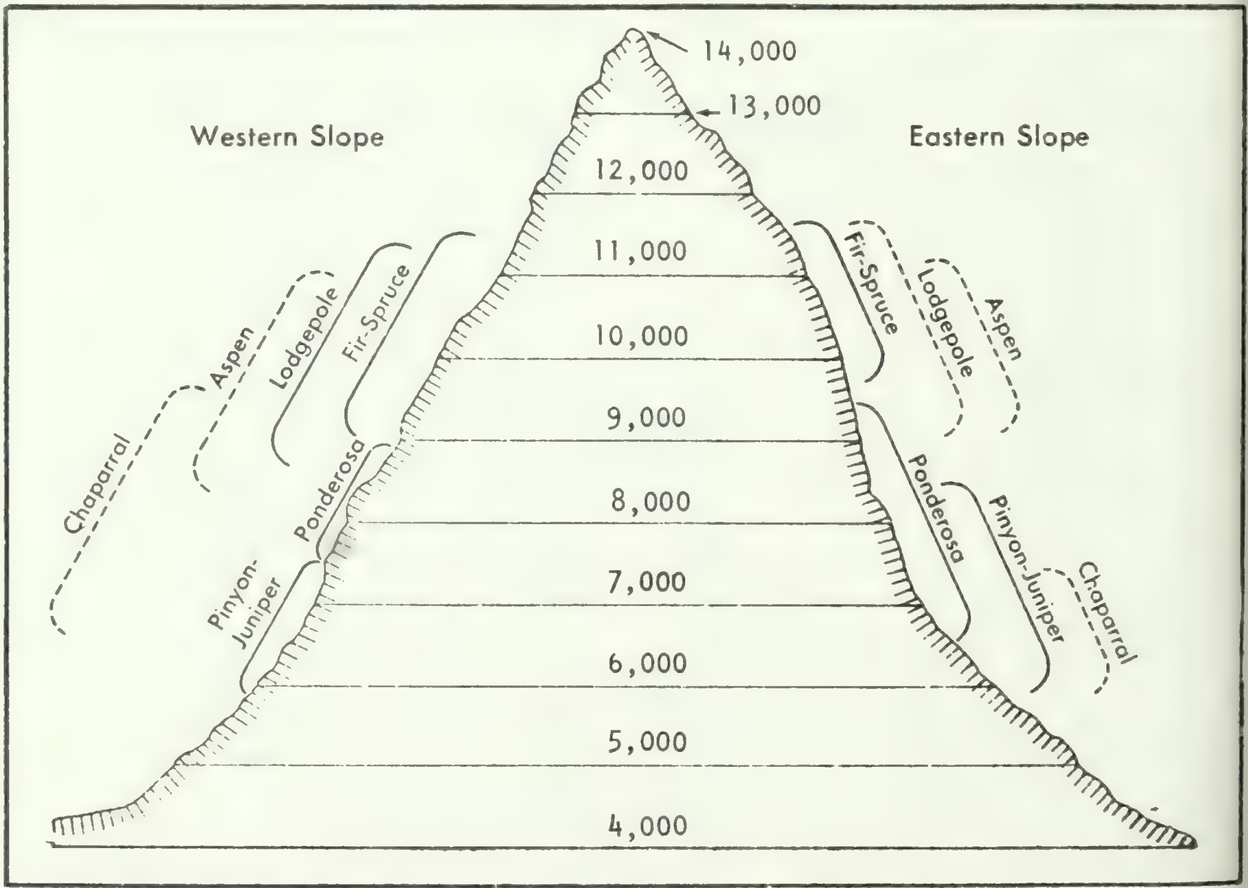
Climate in the zone ranges from semiarid to subhumid, with average rainfall varying from about 15 or 16 inches in New Mexico and south-central Colorado to over 25 inches in the Medicine Bow Range of Wyoming. Altitudinal range of the ponderosa pine type differs between the Eastern and Western Slopes of the Continental Divide (fig. 3).

The distribution and form of precipitation, which are extremely important to plant growth, also vary on each side of the Divide. On the Western Slope, annual precipitation averages 14 to 18 inches in the pine type. About half of this precipitation comes as snow through the fall and winter months, and half as rain between April and September. June tends to be rather dry. The severely cold, Arctic air masses that frequently dominate the Eastern Slope, and particularly the Central Plains, only occasionally influence temperatures on the Western Slope. Thus minimum temperatures are more moderate. Otherwise, temperatures are rather comparable for the two ponderosa pine areas.

On the Eastern Slope, daily temperatures rang from an average maximum of about 50°F in Januar and February to approximately 85°F in July an August. Seldom do daytime temperatures excee 90°F. These same months have the lowest and highes minimum daily temperatures, which average abou -10°F in the winter to about 35°F in the summer. Th growing season is rather short, about 125 days. Extreme cold from Arctic air is not uncommon, an temperatures may drop to -40 to -50°F for shor periods.

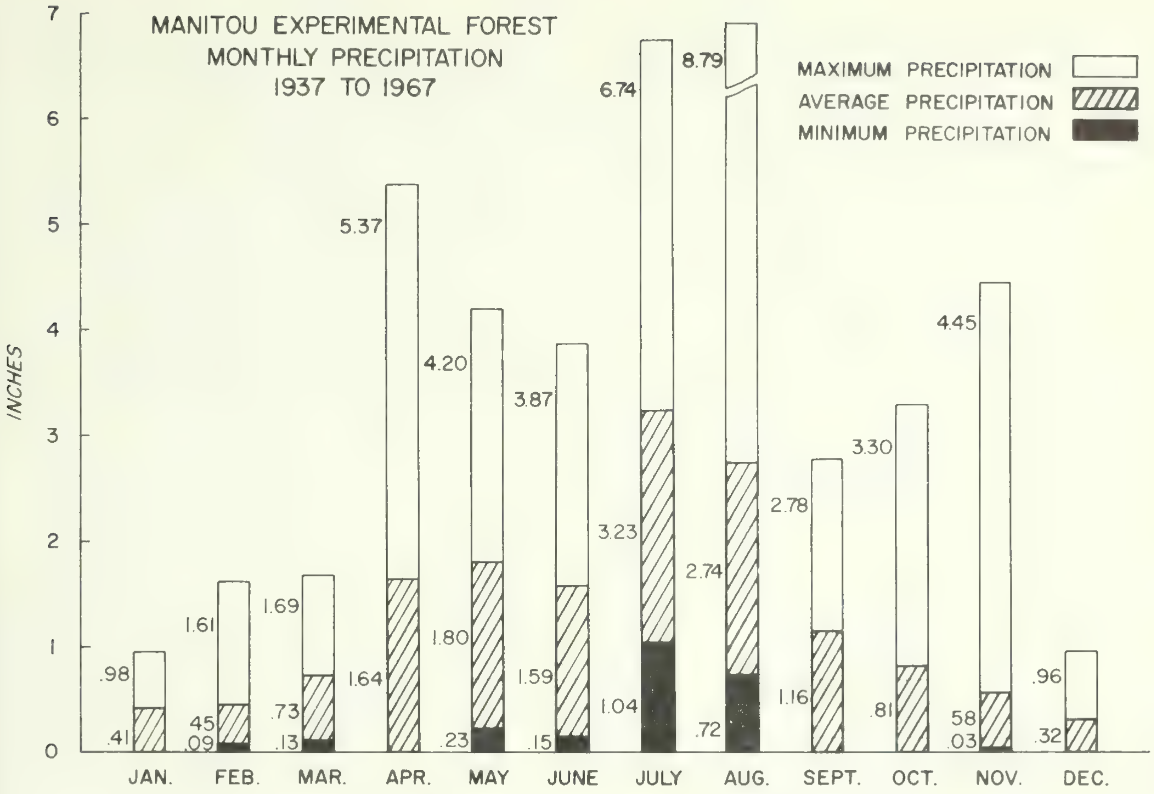
Precipitation on the Eastern Slope generally range between 12 and 20 inches. The summary of 30 years precipitation (fig. 4) for the Manitou Experimenta Forest, Colorado, is characteristic of that for th Eastern Slope pine type. Commonly, two-thirds o more of the annual precipitation is received durin the period from April through September, with July and August being the wettest months.

On both sides of the Continental Divide, the number of clear days averages 100-140 (Reifsnyder and Lull 1965). The average number of cloudy days averages between 80 and 120. The remainder ar



Adapted from "The Principal Forest Types of Colorado as related to Altitude" by Herbert E. Schwan.

Figure 3.—The principal forest types of Colorado as related to altitude; broken lines indicate subclimaxes (from Miller and Choate 1964).



igure 4.—Summary of monthly precipitation data, Manitou Experimental Forest, 1937 to 1967.

rtly cloudy days brought about by the summer infall patterns characteristic of the pine type. orms are a result of mass air disturbances initiated early morning heating. When these local warm nvection currents rise and meet the cool air coming om the higher mountains, severe thunderstorms ay result. With the exception of these cloudburst orms, which produce large amounts of rainfall in ort periods, the climate in the ponderosa pine zone more moderate than on the adjacent Central ains.

Vegetation

The pine-bunchgrass type of the central Rocky ountains is a complex of plant communities. Its e apparent and common characteristic, however, is t of open grassland parks interspersed among ested areas (fig. 5). On north slopes at high vations in the western portion of the ponderosa e-bunchgrass type there is a gradual mergence h the spruce-fir type, or with the lodgepole pine

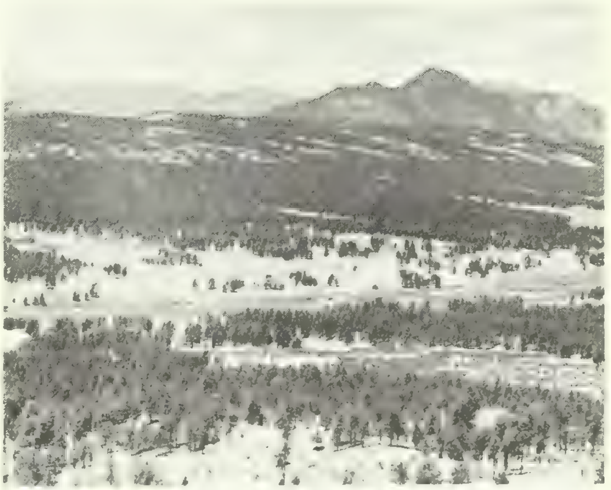


Figure 5.—The ponderosa pine-bunchgrass type is characterized by open grasslands interspersed within the tree community. On the higher ridges and north slopes (background), ponderosa pine merges with the spruce-fir or lodgepole pine types.

type described by Alexander (1974). Along the eastern margin, a series of north-south hogbacks and foothills are covered with a mixture of ponderosa pine, mountain brush, and native grasses. In the southern portion, the eastern areas support stands of pinyon-juniper that intergrade with ponderosa pine as the land slopes upward to the west.

Ponderosa pine-bunchgrass ranges include four vegetation subtypes of special interest. The largest subtype productive for grazing consists of open stands of timber with an extensive herbaceous understory (fig. 6). In the northern part of the type, Idaho fescue is prominent, but is replaced by Arizona fescue to the south. Mountain muhly, blue grama, Parry oatgrass, sedges, and a variety of forbs are common throughout the type. These same species comprise the vegetation of the open grassland parks, but usually in much more dense stands. The open parks along watercourses give way to meadows and streambanks covered with sedges, rushes, hairgrasses, wheatgrasses, and willows. The fourth subtype is composed of closed stands of ponderosa pine with almost no understory, but with a litter mat of needles and small twigs, or at higher elevations or
on north exposures, mixtures of pine and Doug
fir. Grass cover varies in density from lush mead
to an extremely thin and patchy cover on ste
unstable, south-facing slopes.

In the southern half of the ponderosa pine ty
oak brush has invaded cutover pine stands. In m
places the oak brush is of sufficient density to
classified as a separate type. As a result of past f
or other disturbances, quaking aspen mixed v
ponderosa pine sometimes occupies large acrea
very productive for grazing (fig. 7). In New Mex
shrubby cinquefoil is also abundant on depleted s
within the pine type. These areas generally hav
low potential for grazing unless the species comp
tion is improved.

As many as 35 species of grasses are present
ponderosa pine ranges in good to excellent condi
(Johnson and Reid 1958). Forbs are also numer
but fluctuate from year to year, with only a
species frequent or abundant enough to war
consideration. On average pine-bunchgrass ran
generally only six forage species — little bluest
blue grama, Arizona fescue, mountain muhly,
sedge, and fringed sagebrush — make up about
percent of the herbage composition by weight.

Costello and Schwan (1946) considered each of
plant communities in the pine type to be a tra
tional stage between bare ground and the ultim
pine or fir climax forest (fig. 8). Of partic
interest from the grazing standpoint, however,
the intermediate stages of any one of a hundred
more communities that are influenced by such thi
as livestock use, timber management activities, f
base geology, soil type, and other influences.

Generally, range managers have attempted
retain or achieve the fescue-mountain muhly s

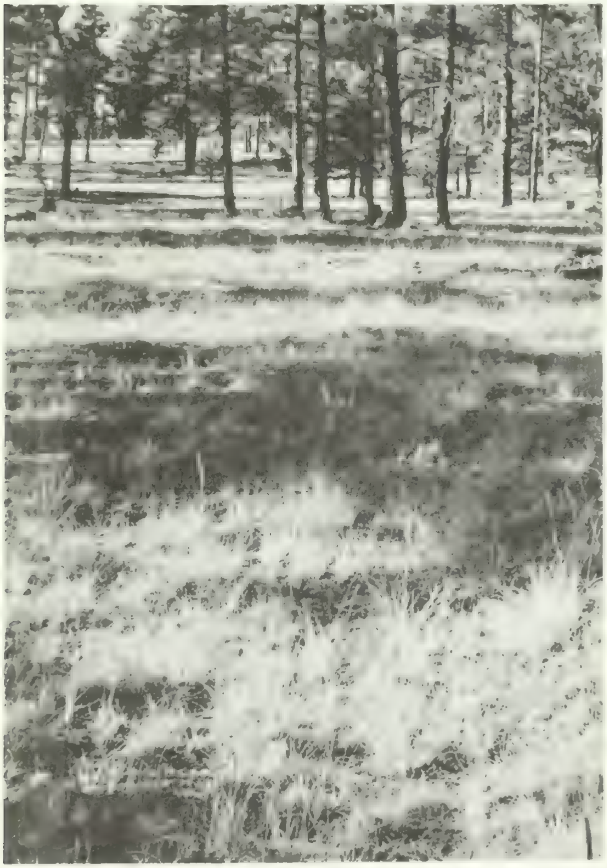


Figure 6.—Open stands of ponderosa pine occupied by good stands of the dominant grasses and forbs constitute the largest subtype productive for livestock grazing.

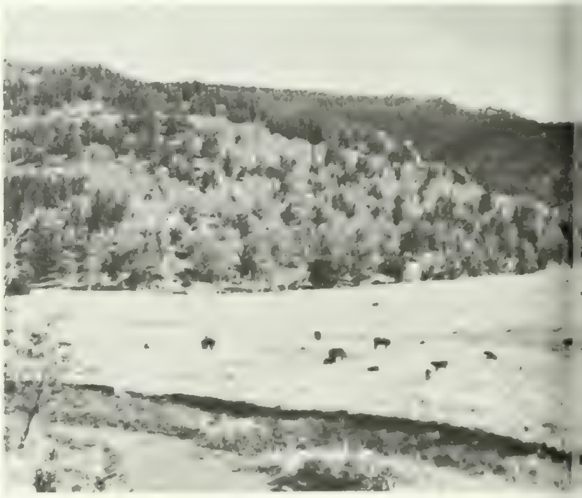


Figure 7.—Quaking aspen mixed with p
derosa pine forms large communit
throughout the pine type.

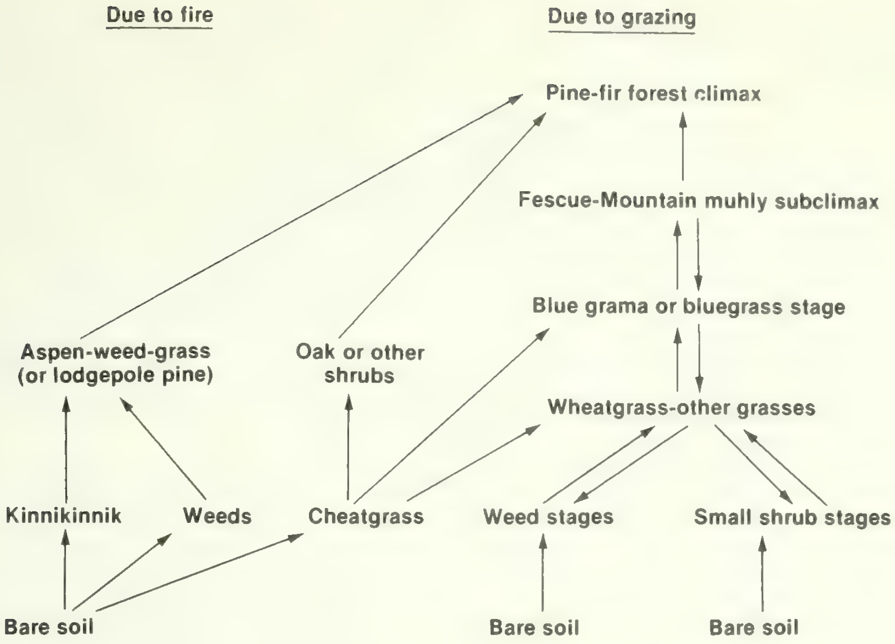


Figure 8.—Some common secondary successions in the ponderosa pine zone (from Costello and Schwan 1946).

climax. This stage is characterized by an abundance of Arizona fescue and mountain muhly in the southern two-thirds of the zone. Idaho fescue usually replaces the Arizona fescue toward the northern border of Colorado and into Wyoming. At the upper limit of the pine zone, Thurber fescue will replace Arizona fescue, and it may be associated with the Idaho fescue. In the Southwest, this association may have substantial amounts of sheep fescue.

In addition to the fescues and mountain muhly, other desirable grasses are Parry oatgrass, Junegrass, and little bluestem. Those of lesser importance include blue grama, western wheatgrass, slender wheatgrass, and bottlebrush squirreltail. Other less desirable grasses are sleepygrass, pullup muhly, and tumblegrass.

Among the less transient and usually conspicuous forbs are Fremont and Parry geraniums, purple milkvetch, western yarrow, Lambert loco, cinquefoils, asters, and bluebells. Less common forbs which are usually present but not abundant if ranges have been well taken care of include: hairy goldaster, trailing fleabane, and fringed sagebrush.

Early Grazing Use and Direction for Research

The bulk of grazing management research in the ponderosa pine-bunchgrass type of the central Rockies has been done at the Manitou Experimental Forest, 28 miles northwest of Colorado Springs. Most of the virgin ponderosa pine on the Experimental Forest was cut over between 1880 and 1885. Some of the cutover and natural openings were plowed and cultivated in the late 1800's and early 1900's. Between 1912 and 1933, from 225 to more than 300 head of cattle and horses grazed these lands. The use period was quite long, May 1-December 15, and generally heavy. This heavy use — and sometimes abuse — which disturbed or removed the plant cover, in combination with the inherent high erosion hazards of the granitic soils in the pine type, prompted early research to be directed toward erosion-related problems. Thus, early grazing management research was directed toward the broader aspects of proper management and grazing as it related to watershed problems.

Several grazing studies were started when the Manitou Experimental Forest was established in 1937. One of the first problems evaluated was that of surface runoff and erosion (Dunford 1954). Six 1/100-acre plots were measured in the bunchgrass type over a period of approximately 20 years. The plots were distributed in two batteries of three each, lying on a 17-percent north-facing slope. Vegetation was primarily grasses, dominated by Arizona fescue and mountain muhly. The relatively permeable soil originated from gravelly alluvium and outwash of Pikes Peak granite.

Following a 4-year calibration period, cattle grazing treatments were initiated in 1941. Two plots were grazed heavily, two moderately, and two were left ungrazed as controls (fig. 9). Pretreatment calibrations had estimated that runoff was substantially the same, 0.24 to 0.27 inch per season, on all plots during the summer rainfall period. In 12 years of grazing, moderately grazed plots average 0.22 inch of runoff per season and heavily grazed averaged 0.34 inch per season. Nongrazed plots averaged 0.11 inch per season. This was equivalent to the surface runoff and soil losses shown in figure 10.

Erosion occurred almost exclusively during the months of July and August. During calibration, average erosion for the summer period varied from 111 to 163 pounds per acre. After grazing treatment, annual soil loss from moderate grazing averaged 145 pounds per acre for 13 rainstorms, heavy use 316 pounds, and nonuse 134 pounds per acre.

Vegetation on the moderately grazed plots of this study (Dunford 1954) was quite comparable to that on range described as being in good condition by Reid and Love (1951) for the Elk Ridge area on the Roosevelt National Forest. Infiltration rates on plots in good condition were 118 percent greater than on plots in very poor condition, 80 percent greater than those in poor, and 35 percent greater than for plots in fair condition. Also, erosion rates from plots in good condition were about one-fourth those from plots in very poor condition, and one-half those in fair condition.

In the same study, Reid and Love (1951) analyzed principal uses and values of the area, including surveys to determine forage condition and trend in the vegetation complex. They concluded that range improvement would have little overall effect on watershed conditions because the principal areas utilized by cattle were grassland types which occupy only a small part of the total watershed. They furthe concluded that tree overstory, rather than grazin was the most important factor in reducing runo and erosion, particularly on south exposures.

From this work in reference to watershed pr tection, it was concluded that a moderate rate grazing is not detrimental. On the flat open areas gentle slopes where cattle usually graze, removin about 35 percent of the current growth will n adversely affect the watersheds. Heavy grazin where about 50 percent or more of the herbage removed, will subject the soils of the pine type to a accelerated erosion rate considered to be above no mal.

Plant and Animal Management on Native Ranges

Other early studies were devoted to determinin optimum grazing intensities for maintenance of pla cover and beef production on native ranges. Johnso (1953) summarized the results of these intensity-o use investigations from 1941 through 1947. Smi (1967) incorporated later and more comprehensi data into a bulletin on how ponderosa pine-bunc grass ranges should be grazed. It included discu sions of effect of grazing intensity on plant growt cattle gains, and soil responses, and relation grazing intensity to income.

Herbage yields and associated stocking rates a extremely variable on ponderosa pine-bunchgra ranges. The yields of grass and sedge herbage vari from about 50 to 75 pounds per acre under den timber to approximately 1,200 pounds per acre moderately stocked open grasslands (fig. 11). Gras

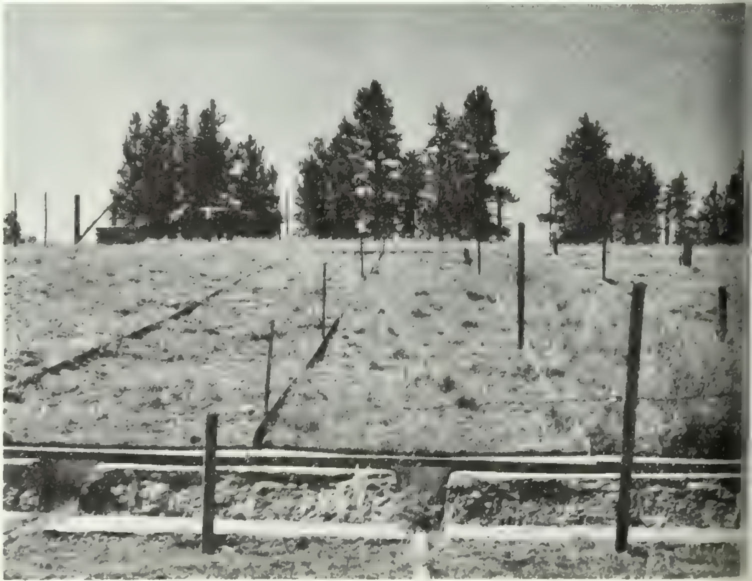
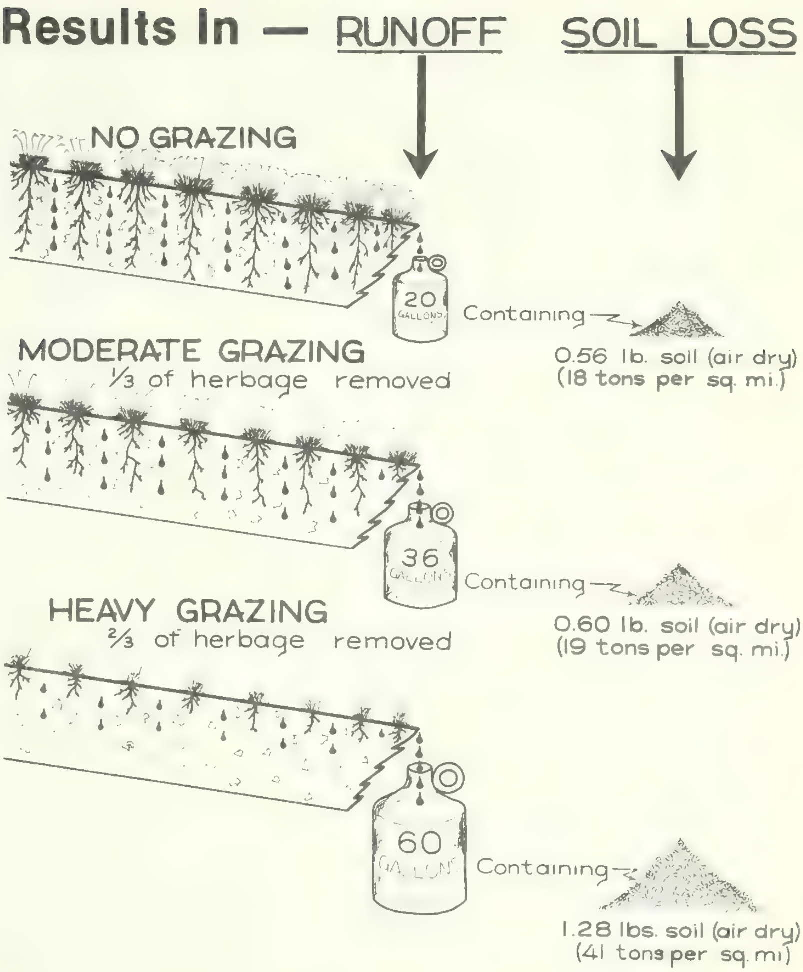


Figure 9.—Heavy cattle grazing on 1/100-acre plots increased surface runoff and soil losses over open grasslands of the pine-bunchgrass type (adapted from Dunford 1954).



igure 10.—The degree of grazing use substantially affects surface runoff and soil loss when more than half of the herbage is removed. Moderate grazing that removes about one-third of the available herbage also increases surface runoff, but does not increase the soil loss much above that from ungrazed range (from Dunford 1954).

nds protected from grazing produce yields of up to ,600 pounds per acre. Smith (1967) reported that, fter 17 years of treatment, the annual yields of rasses and sedges were maintained under light or oderate use, but heavy grazing substantially reuced yields. Plant species contributing to these elds were influenced by grazing use. As shown elow, the major bunchgrasses were favored by light moderate grazing, while undesirables increased ith heavier use:

Favored by light and moderate grazing	**Favored by heavy grazing**	**Not affected by degree of grazing**
Mountain muhly	Tumblegrass	Sun sedge
Arizona fescue	Pussytoes	Fringed sagebrush
Blue grama	Groundsels	
Bottlebrush squirreltail	Goosefoot	
Lupines		
Bearberry		
Arkansas rose		

Degree of livestock use was also closely associated with cover types. Most of the livestock grazing was on abandoned fields or the open grassland parks. Cattle grazed some under the open timber type, but the dense timber type was seldom grazed. Where approximately 35 percent of the range is open grassland, 60 percent is open timber, and 5 percent dense timber, about 3.5 to 4 acres are required to graze a yearling animal for a month. If cows and calves are being grazed, about 10 acres are required per pair. These figures are average stocking rates for ranges in fair condition, and will vary with changes in cover type, grazing season, and climatic variables, particularly rainfall.

Stocking rates also depend on such things as size and age of animals, topography or steepness of slope, range condition, and cover type. Rates may vary from as few as 2 to 3 acres to as many as 8 to 15 acres per animal unit month (AUM), depending on slope, condition, and cover type (Costello and Schwan 1946):

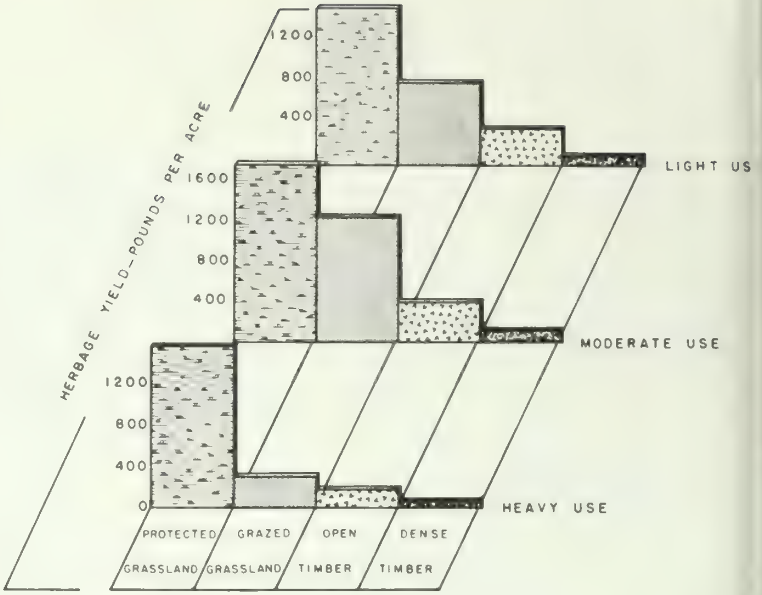


Figure 11.—Herbage yields from pine-bunchgrass ranges vary extremely with cover type. This variability is further modified by degree of grazing use. Moderate grazing provides the largest sustained herbage yields (from Smith 1967).

Range condition and percent slope	Acres per AUM
Excellent:	
<20	2-3
20-40	3-4
>40	4-6
Good:	
< 20	3-4
20-40	4-6
40-60	6-12
Fair:	
<20	4-8
20-40	6-12
>40	Ordinarily no grazing
Poor:	
<20	8-15
20-40	Ordinarily no grazing
>40	Ordinarily no grazing

Johnson (1953) and Smith (1967) showed that ponderosa pine ranges should be grazed to use 30 to 40 percent of the current annual growth of the major forage grasses to obtain maximum sustained production of both forage and beef. Lighter rates were not harmful to the vegetation, but they were not conducive to a good rate of livestock production. Grazing in excess of 50 percent use of the major grasses resulted in lower livestock production, and harmful, long-lasting damage to the range.

Johnson and Reid (1958) further emphasized that seasonal aspects should be considered in grazing ponderosa pine ranges. Seasonlong summer use was not harmful to pine-bunchgrass ranges, but a range that had a large percent of its forage contributed b Arizona fescue, sedges, or little bluestem would be be used early. Ranges with a predominance mountain muhly are more suitable for mid- to lat season grazing. These conclusions were based on th observations that Arizona fescue is an early coo season species, while mountain muhly makes th bulk of its growth late in the season (Smith 1967).

Ponderosa pine-bunchgrass ranges are normall ready for grazing between June 1 and 15, and can b grazed to as late as November 1 to 15. This late fa grazing, however, is not conducive to the best liv stock production for yearling animals. After Septem ber, animals may frequently lose weight or mak almost no gains. The best gains are made early in th grazing season, with a gradual decline each mont through September (fig. 12). In general, yearlin animals will gain about 1.5 pounds per day in 5-month season (Smith 1967).

To obtain the 30 to 40 percent recommended us stubble heights of Arizona fescue plants shoul average 5 to 6 inches at the end of the grazin season. Mountain muhly will average a 1½- to 2-inc stubble when properly used. At these rates, som plants of each species will remain ungrazed whil others will be grazed more than the recommende rate. Other species generally will not need to b considered for determining range condition.

Complementary work on native species by Schust (1964) showed that root systems of several plants including the major grasses, were reduced by heav grazing (table 1). Differences were not significan between moderately grazed and ungrazed plants however. Root systems of less desirable species suc as blue grama and Rocky Mountain pussytoes in creased or stayed about the same under heav grazing.

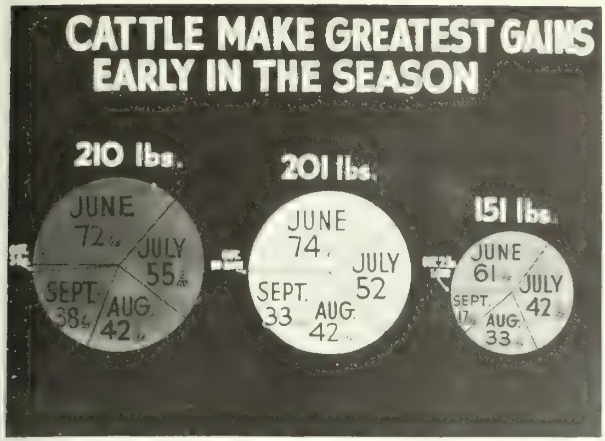


Figure 12.—Yearling animals make their best weight gain on native ponderosa pine-bunchgrass ranges through the summer months. Gains are good from light or moderate grazing, but decrease appreciably when ranges are used heavily (from Smith 1967).

Infiltration of water and erosion of soil were also related to cattle use of the plant cover. Studies by Love (1953, 1958), Renner and Love (1955), and Dortignac and Love (1960, 1961) showed that infiltration rates remained high or good under moderate grazing, but were poor under a heavy rate of use. They also showed that, if an area is first grazed, and later a portion of the range is excluded from grazing, infiltration increases with time on the excluded areas but not on the grazed areas. Thus the main effect of any degree of cattle grazing was to slow or prevent recovery of water infiltration rates.

Soil losses were much greater on heavily grazed ranges where cattle removed 50 percent or more of the herbage than where 40 percent or less was removed on moderately or lightly grazed ranges (Dunford 1954, Renner and Love 1955, Dortignac and Love 1960). However, even the loss of 400 pounds per acre per inch of runoff on heavily grazed ranges was not considered excessive (Dortignac and Love 1960). Relatively small amounts of soil will be washed from ponderosa pine ranges when erosion rates, as determined by the infiltrometer method, are less than 500 pounds per acre.

Grazing of ponderosa pine-bunchgrass ranges also influences the populations of small mammals.[3] Populations of six rodent species were larger on areas protected from grazing than on adjacent grazed ranges. The **degree** of grazing use did not make any measurable difference in these small mammal populations, however. The rodents preferred either an ungrazed grassland range or an open timber type:

Grassland	**Open timber**
Northern pocket gopher	Deer mouse
Meadow vole	Golden-mantled ground squirrel
Thirteen-lined ground squirrel	Colorado chipmunk

Any degree of cattle grazing functioned as a control measure to keep populations lower than on ungrazed areas. Regulation of the height of herbaceous ground cover was evidently the controlling factor in both types.

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[3] *Reid, Vincent H., Wildlife Biologist, Res. Bur. Sport Fish. and Wildl., USDI Fish and Wildl. Serv., Fort Collins, Colo. (Manuscript in preparation, "Populations of certain rodents on grazed and nongrazed ranges.")*

Table 1.—Depth and spread of root systems in relation to grazing of the most common native plants on pine-bunchgrass ranges (from Smith 1967).

Species	Average maximum depth			Average maximum lateral spread[1]		
	No use	Moderate use	Heavy use	No use	Moderate use	Heavy use
	In.	*In.*	*In.*	*In.*	*In.*	*In.*
Arizona fescue	44.5	44.1	31.3	12.0	11.3	8.0
Blue grama	37.8	42.8	36.0	9.3	7.4	7.1
Fringed sagebrush	38.2	38.7	26.4	6.4	8.8	6.1
Mountain muhly	50.8	44.1	32.1	11.4	8.9	6.8
Rocky Mountain pussytoes	14.0	14.0	19.0	5.0	10.5	5.8

[1] Measured from line projected through plant center.

Establishing and Management of Seeded Ranges

The incorporation of seeded ranges into management systems resulted from extensive early investigations into revegetation practices. For example, during the late 1800's and early 1900's, areas of the pine type were cultivated for a number of years, then abandoned without provision for establishment of vegetative cover (fig. 13). When Johnson (1945) observed secondary successional stages of natural revegetation of abandoned croplands, he concluded that overgrazing could maintain a stand of inferior plants indefinitely. Even with proper management, these ranges were slow to recover, and plow lines associated with characteristic vegetation were readily apparent almost 100 years later. Seeding, however, could restore these areas to a productive condition in a few years (Johnson 1947). Thus, much emphasis c early reseeding work centered largely on plantin techniques and species adaptability tests.

On both native and reseeded ranges, the relatio of forage removal to soil and vegetation growt received attention before systems-of-grazing exper ments were included in research programs. Researc on specific relations and responses of individu species are developments of the last few years.

Adaptability and Seeding Methods

Investigations of range reseeding within the pon derosa pine zone have been concentrated largely a the Manitou Experimental Forest. Study of plantin techniques and species adaptability were importan phases of the early research (fig. 14). Johnson an

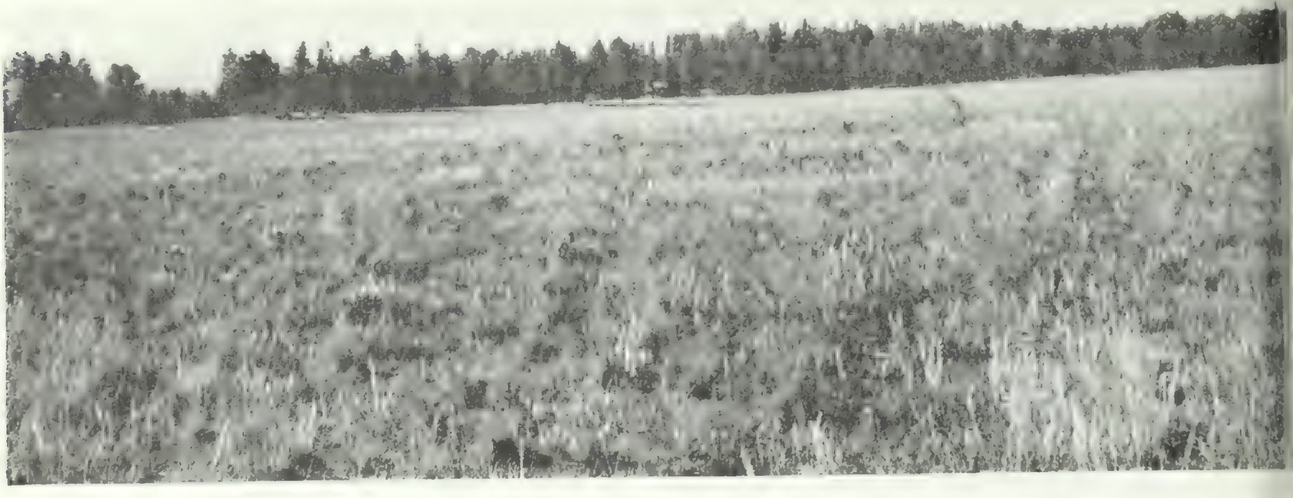
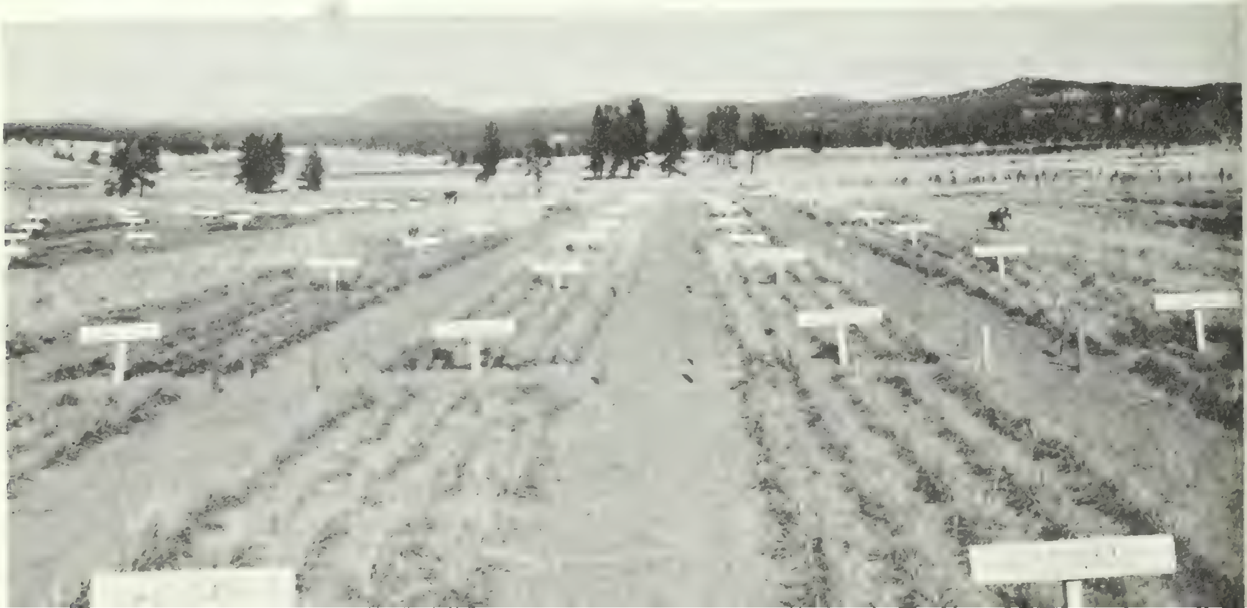


Figure 13.—Abandoned fields in the pine type produce only small amounts of low-quality forage. These areas were turned into highly productive cattle ranges by seeding, mainly to introduced grasses or grass-legume mixtures.

Figure 14.—Species adaptability tests were used to establish success ratings for a large number of forage species, varieties, and strains in the pine type (from Hull and Johnson 1955).



Hull (1950) and Hull and Johnson (1955) summarized recommendations of this early research. In addition to the work carried out at Manitou, 14 experimental areas and 391 range seedings were observed throughout the ponderosa pine type. This study resulted in many basic suggestions concerning where, when, what, and how to seed (McGinnies et al. 1963). Another valuable contribution was the development of establishment success ratings for 121 forage species, varieties, and strains. Ratings for the most promising species tested are summarized in table 2 (Hull and Johnson 1955).

Open parks in the pine type have the best economic potential for improvement by seeding, particularly if the areas have been abused and are supporting plants of low to medium quality for grazing. Such areas are characterized by an abundance of species such as sleepygrass, blue grama, trailing fleabane, or fringed sagebrush. Abandoned fields are also particularly suitable for seeding (Johnson and Hull 1950).

Seeding success is closely related to the effort expended in seedbed preparation and elimination of competing vegetation. Excellent stands were commonplace if the best-adapted species were used, and seedbed preparation consisted of moldboard or brushland plowing or using a heavy offset disk (fig. 15). Medium disks or sweeps resulted in good stands. Chisels and field cultivators resulted in only fair to poor stands.

Early-spring and medium- to late-fall plantings gave the best stands in lower elevations of the pine zone. Generally March and early April have enough moisture for seeding in the spring, and fall seeding in October and November is reasonably successful. In the higher part of the zone, both total and higher seasonal moisture permits seeding in April and May on well-prepared seedbeds. September and early October is usually best for fall seeding. In southwestern Colorado and northern New Mexico, seeding in July and August gives good results. Generally, seeding results are more dependable from fall than spring seeding (Hull and Johnson 1955).

Although Sherman big bluegrass appeared to be well adapted and showed promise for grazing in early studies, seedings often failed (McGinnies et al. 1963). Further establishment testing (Currie 1967) showed the species was best established by planting in July or August into a moist seedbed that had been summer fallowed (fig. 16). Controlling the depth of planting to 5/8 inch by means of a double-disk, depth-band drill gave the best results. Roadside stabilization programs with this and other species, seeded in summer, have been successful in the pine type in the Colorado Springs area.

Table 2.—Establishment success rating of species tested on 391 seedings throughout the pine zone of Colorado (from Hull and Johnson 1955).

Species	Times seeded	Seedings by class				
		Excellent	Good	Fair	Poor	Failure
	No.	*No.*	*No.*	*No.*	*No.*	*No.*
Crested wheatgrass	265	64	127	27	21	26
Smooth brome	195	31	88	25	24	27
Yellow sweetclover	153	17	60	26	30	20
Alfalfa	34	4	25	-----	1	4
Timothy	16	-----	8	2	4	2
Intermediate wheatgrass	13	7	5	1	-----	-----
Orchardgrass	9	-----	3	1	3	2
Western wheatgrass	8	1	-----	3	4	-----
Kentucky bluegrass	7	-----	-----	1	3	3
Slender wheatgrass	6	-----	1	-----	5	-----
Alsike clover	5	1	1	1	-----	2
Quackgrass	4	3	1	-----	-----	-----
Big bluegrass	4	2	1	-----	-----	1
Tall oatgrass	4	-----	2	-----	1	1
Redtop	3	-----	3	-----	-----	-----
Bulbous bluegrass	3	-----	-----	1	1	1
Russian wildrye	2	1	-----	1	-----	-----
Blue grama	2	-----	-----	-----	1	1
White clover	2	-----	-----	1	-----	1
Perennial ryegrass	2	-----	-----	-----	-----	2

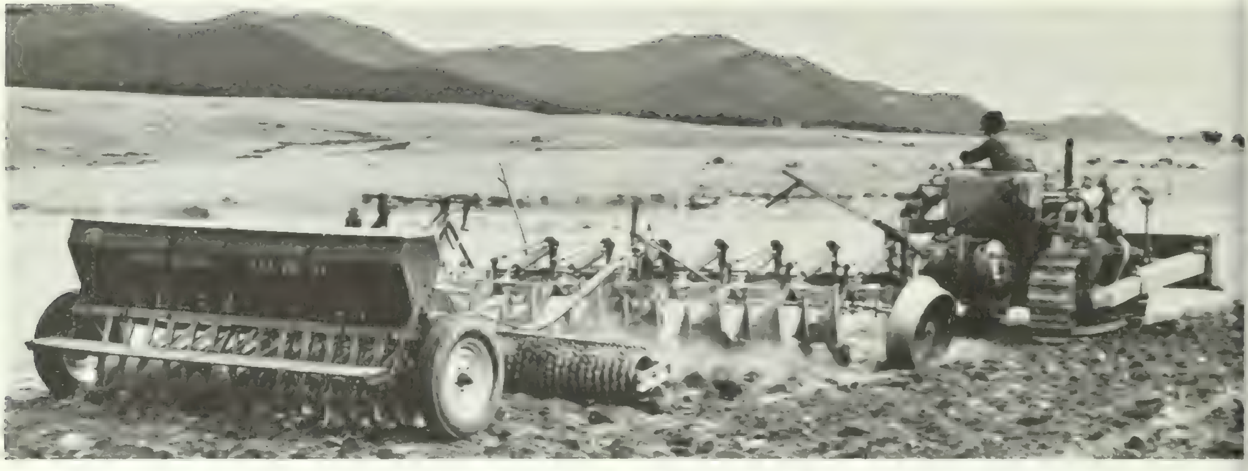


Figure 15.—A variety of equipment was tested and used for seeding establishment in the pir type. Plowing with the brushland plow, cultipacking to firm the seedbed, and planting with grain drill were used in one operation to minimize costs on suitable areas (from Hull an Johnson 1955).

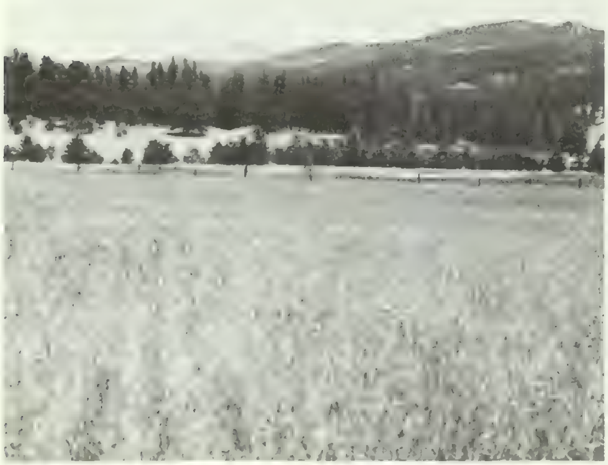


Figure 16.—Excellent stands of Sherman big bluegrass were obtained by planting into a moist seedbed in July or August. Such stands are characteristic of the potential for abandoned fields in the pine type (from Currie 1967).

Grazing Management

Management studies on reseeded pastures at Manitou Experimental Forest have concentrated on the effects of grazing intensities. Four species — smooth brome, crested wheatgrass, intermediate wheatgrass, and Russian wildrye — and a mixture — smooth brome - crested wheatgrass - yellowblossom sweetclover — were subjected to different intensities of grazing. In 1952, Johnson presented guidelines[4] for grazing reseeded pastures that were based large on the work conducted at Manitou, followed by published interim report that summarized the effec of grazing on seeding species (Johnson 1959). comprehensive final report was published by Curr and Smith (1970).

During 14 years of grazing, a mixture of creste wheatgrass, smooth brome, and yellowblosso sweetclover gave the best sustained forage and liv-stock production. The average per-acre weight gai for yearling heifers was highly variable by species an from year to year, however (table 3). This variatio was directly related to forage production, which wa low in dry years and high in wet years (fig. 17). Fo example, per-acre gains from the mixture average only 12.8 pounds in 1954 when growing-season rai fall was 9.03 inches, but went up to 99.8 pounds pe acre in 1957 when rainfall was 15.62 inches. Creste wheatgrass showed a similar trend, with gains bein about eight times more in wet years than dry years.

Although sweetclover died out within a few yea after planting, its initial influence made it wort including in new seedings. Smooth brome and inte mediate wheatgrass also are recommended in mi ture plantings, even though neither species held u well individually under any of the grazing intensitie studied. However, both species provided good dail gains, per-acre gains, and high grazing capacities i the early years of treatment which justified thei inclusion in mixture plantings. Daily gains decrease as they died out, but overall yields of forage and bee were greater than on crested wheatgrass seeded i pure stands.

Grazing of mixture ranges can begin in the sprin when maximum leaf lengths average approximatel 4 inches on the crested wheatgrass plants. Thes ranges should then be stocked heavily enough t

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[4] *Johnson, W. M. Management of reseeded pastures. Paper presented to Colorado Grassland Committee, Jan. 22, 1952.*

Table 3.—Weight gain of yearling cattle from seeded ranges that are best adapted to the ponderosa pine type (from Currie and Smith 1970).

Year	Seasonal per-acre weight gains				
	Crested wheatgrass	Smooth brome	Mixture	Intermediate wheatgrass	Russian wildrye
			Pounds		
1948	82.2	75.4	85.5	—	—
1949	98.3	83.7	126.3	—	—
1950	50.0	35.0	60.1	83.7	—
1951	44.1	35.7	48.7	43.3	38.0
1952	76.3	62.1	77.8	64.8	51.6
1953	56.8	48.0	68.2	63.6	53.8
1954	10.3	2.8	12.8	12.0	10.3
1955	64.5	38.5	86.3	64.4	82.0
1956	54.0	33.2	65.6	58.6	65.6
1957	79.7	37.2	99.8	57.8	67.3
1958	42.0	18.0	65.6	43.7	28.6
1959	52.7	13.4	62.4	31.0	42.4
Average	59.2	40.2	71.6	52.3	48.8

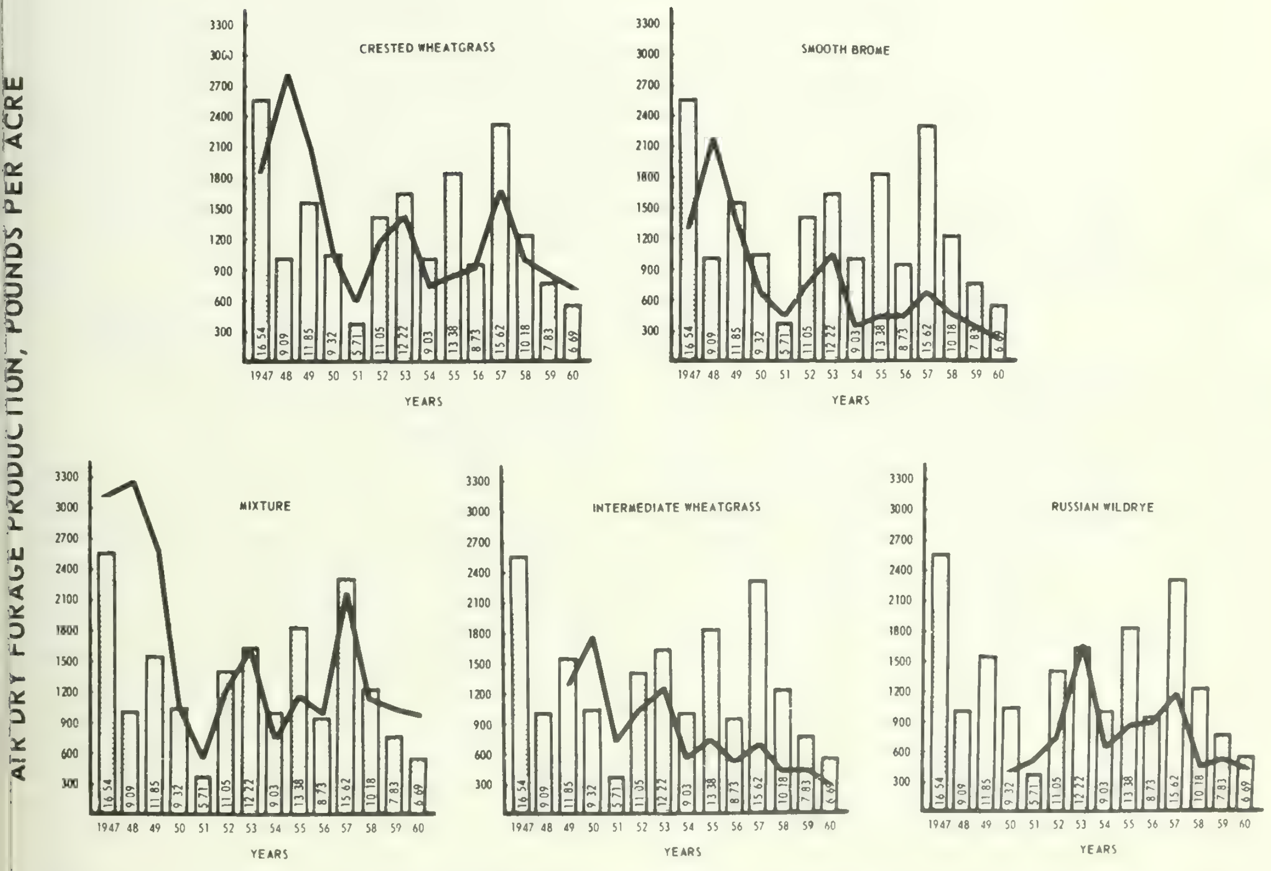


Figure 17.—Pounds per acre of herbage produced by seeded species in relation to the amount of growing-season precipitation (from Currie and Smith 1970).

make uniform use of the available forage. Grazing to a 2-inch stubble height, or approximately 65 percent use of the forage by weight, is recommended. Springfield (1963) made similar recommendations for grazing crested wheatgrass in northern New Mexico: start spring grazing when plants are 4 to 5 inches tall, and take animals off the range when utilization averages 65 to 70 percent.

Ground cover, particularly litter, may be reduced with these heavy rates of utilization, but invasion by undesirable species will not be much greater than from grazing at lighter intensities. The advantages of a good level of forage production, more uniform utilization, and greater animal gains per acre, make grazing to a 2-inch stubble height preferable to grazing at a lighter rate unless the additional cover is needed for erosion control and watershed protection purposes.

Russian wildrye, seeded in pure stands, started growth an average of about 3 weeks earlier than other seeded species. Thus where early spring forage is advantageous, this species will provide forage before other seeded species are ready for use. Grazing to approximately a 3-inch stubble height is recommended for Russian wildrye, which should avoid development of ungrazed wolf plants and eventual overgrazed local areas. It should be realized, however, that animal weight gains will usually be smaller than those from ranges seeded to a mixture. Also, Hervey and Johnson (1954) found that Russian wildrye does not fill in between rows following establishment, and concluded that this characteristic may be a disadvantage in high wind or water erosion areas.

Sherman big bluegrass, which was tested later than the other species (Currie 1969a), produced daily gains comparable to crested wheatgrass but less than for intermediate wheatgrass or the mixture. In terms of total beef production and grazing capacity, however, it was superior to any of the other species. Beef production on Sherman big bluegrass averaged 6.7 pounds per acre more than on the mixture, and 19.1 pounds per acre more than on crested wheatgrass. It produced from 54 to 200 pounds more forage per acre, respectively, than these ranges when grazed to a proper 4-inch stubble height. In addition, this species started growth as early as Russian wildrye, and was more drought-tolerant than any of the other species tested.

Crested wheatgrass, which receives the most widespread use in range seedings, was tested to determine which season of use was best for sustained livestock and herbage production (Currie 1970). Grazing this species to a 1-inch stubble height for 10 years during spring only, fall only, or spring and fall, had litt effect on the vegetation. Drought and growing-seaso moisture had more influence on these ranges tha the season of grazing. Pastures grazed in spring and fall produced more forage and gave the highest average beef yields, 177 pounds of gain per season.

A method of stepwise regression analysis was developed for estimating forage yields of crested wheatgrass ranges by measuring the monthly precipitation received during the growing season (Curri and Peterson 1966). Precipitation accounted for 88 t 97 percent of the differences in yields, and th amounts received during different months or combinations of months determined the effective forag production available for use by livestock at eac season. Precipitation received in April primaril determined forage yields on ranges grazed only in th spring. For ranges grazed only in the fall, May-Jul rainfall was most useful for predicting yields. Whe ranges were grazed both spring and fall, April-Ma precipitation determined spring yields and June-Jul rainfall controlled fall forage production.

Stocking rates in relation to forage yields durin the different grazing seasons were also determined Correlation coefficients between stocking rates (y and effective forage production at each season (x ranged from 0.94 for spring grazing on spring-fal ranges to 0.99 for ranges grazed only in the fall (fig 18). The methods of analyses used should be applicable to determining production and stocking rate on many western rangelands, and should also serv as a means of accounting for variation in certai types of research studies.

Cultural Manipulation and Integrated Systems of Management

Cultural Practices

In addition to range seeding, other cultural practices such as herbicide spraying and range fertilization can be used to improve ranges and increase grazing capacities. Abandoned fields (Johnson 1945) or severely depleted ranges (Costello and Schwan 1946) are most responsive to these kinds of treatment. Principal plants which characterize these stands, and will maintain themselves with grazing, are: fringed sagebrush, tumblegrass, trailing fleabane, and hairy goldaster. The more valuable bunchgrasses — Arizona fescue, mountain muhly, and pine dropseed — are present only in scattered or small fragmented clumps. On granitic soils in the pine-bunchgrass type, these species generally responded to applications of a complete nitrogen-phosphorus-potassium (NPK) fertilizer (Retzer

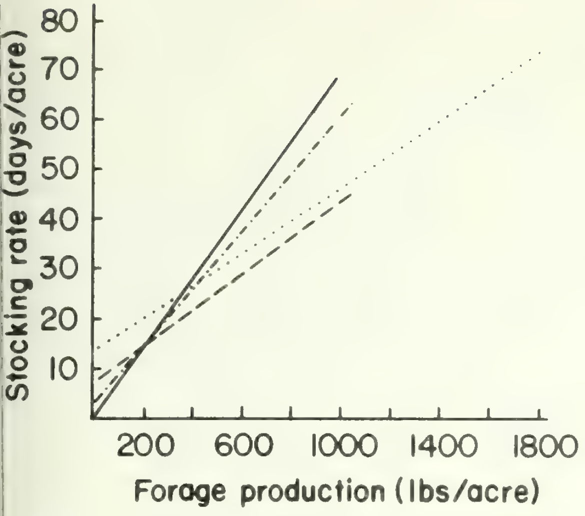


Figure 18.—Stocking rates for crested wheatgrass in relation to forage production and season of grazing (adapted from Currie and Peterson 1966).

(1954). Recent investigations[5] have shown that 50 pounds of elemental material of each fertilizer produces excellent response, and will increase total herbage yields an average of about 500 pounds per acre (including the less desirable species). The more desirable bunchgrasses can be improved by spraying these depleted areas with 2.5 pounds acid equivalent of 2-4 dichlorophenoxyacetic acid (2,4-D). Spraying should be done early in the spring as the temperature in the top several inches of soil reaches or exceeds 50°F. Application of a complete fertilizer in combination with the herbicide treatment enhances growth of the residual grass plants. Fertilization increased herbage yields from native ranges about 500 pounds per acre. Fertilizing plus spraying increased yields about the same amount, but the herbage was mostly desirable grasses not affected by the herbicide:

	1968	1969	1970	1971	Average
Fertilized	2,110	1,778	1,477	686	1,513
Sprayed	690	1,151	1,407	646	973
Fertilized and sprayed	1,627	1,965	1,595	765	1,488
Control	1,044	1,099	1,148	546	959

Fertilization was also used on Sherman big bluegrass to modify the root growth of this species and reduce the ease with which it is pulled up by grazing cattle. Nitrogen or phosphorus alone reduced the tensions required to pull the plants, but N and P together made pulling more difficult than for control plants receiving no fertilizer treatment (fig. 19). Evaluation of plant root systems and top growth in glass-faced planter boxes indicated a close correlation between the total root system weight and the tension required to pull the plants (Haferkamp and Currie 1973).

Integrating Native — Seeded Ranges

Length of the grazing season in which animals make good gains can be substantially increased by including seeded ranges in a management system with native ranges (Currie 1966, 1969b). Average weaning weights of calves grazed on the combination seeded-native range system of management (fig. 20) were consistently heavier than those grazed on native range only:

	Weaning weights on --	
Year	Seeded-native range	Native range
	(Pounds)	
1963	439	422
1964	416	389
1965	462	446
1966	465	420
Average	446	419

For this study, two herds of 12 cows each followed the same grazing system for a 10-year comparison period.

Although most of the weight gain advantage came from fall grazing of Sherman big bluegrass, the Russian wildrye and crested wheatgrass contributed significantly to long-term animal nutrition. Malechek (1966) found that crude protein (fig. 21) was sufficient to excessive for 10 months in the diets of

[5] *Currie, Pat O. Recovery of ponderosa pine-bunchgrass ranges through grazing and herbicide or fertilizer treatments. (Manuscript in preparation at Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)*

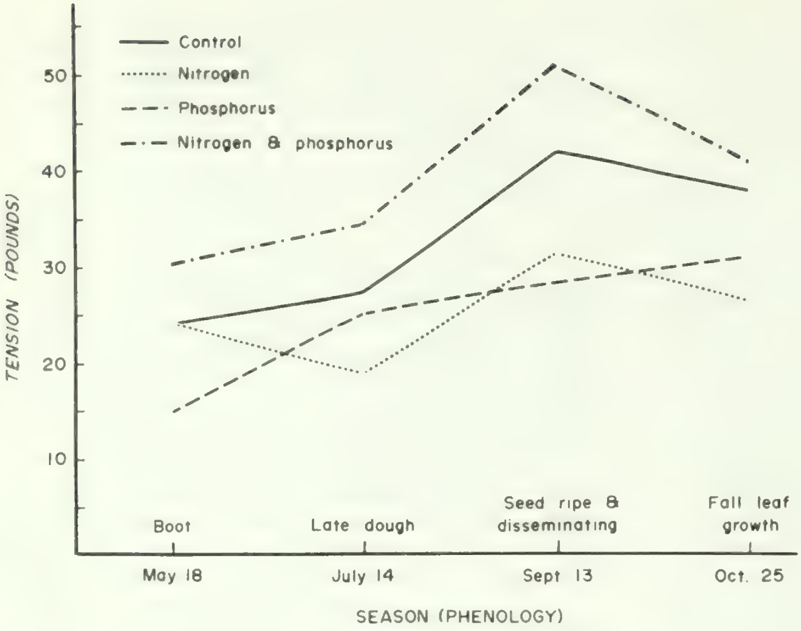


Figure 19.—The tension require for grazing livestock to pull u or break Sherman big bluegrass plants can be modified by adding fertilizer. A combination o 50 pounds each of nitrogen an phosphorus most effectively reduced pullup.

fistulated animals when seeded ranges were integrated into the management system, compared to only 8 months for animals grazing only native forage plants. Earlier growth and later dormancy of the seeded species was largely responsible for the nutritional difference.

Dormant-season grazing of Sherman big bluegrass during November through March minimized the pullup problem of this species, and also produced satisfactory overwinter weight gains (Currie 1975). Big bluegrass usually provided abundant forage for overwintering weaner heifer calves. The animals gained weight in late fall with or without a protein supplement. Weight losses during winter and spring were relatively small, usually averaging less than pounds per animal. Feeding a protein supplement t prevent or reduce such a small weight loss probab is not justified. In addition, big bluegrass supported two to three times more animals than a comparab acreage of native range, and when supplemented with ¼ or ½ pound of protein produced nearly twi as many pounds of beef per acre as did native rang

Additional Practices

Several universally recognized range management practices are applicable for improving livestock di

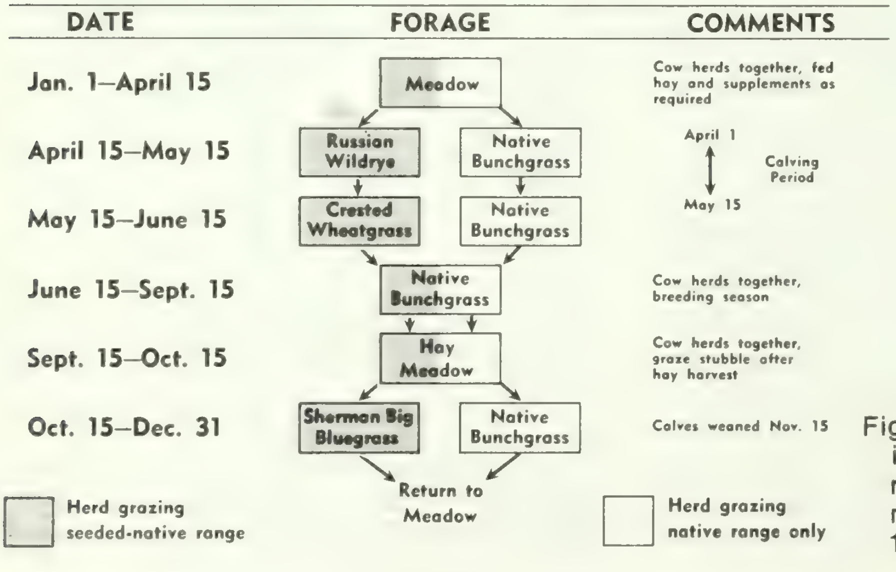
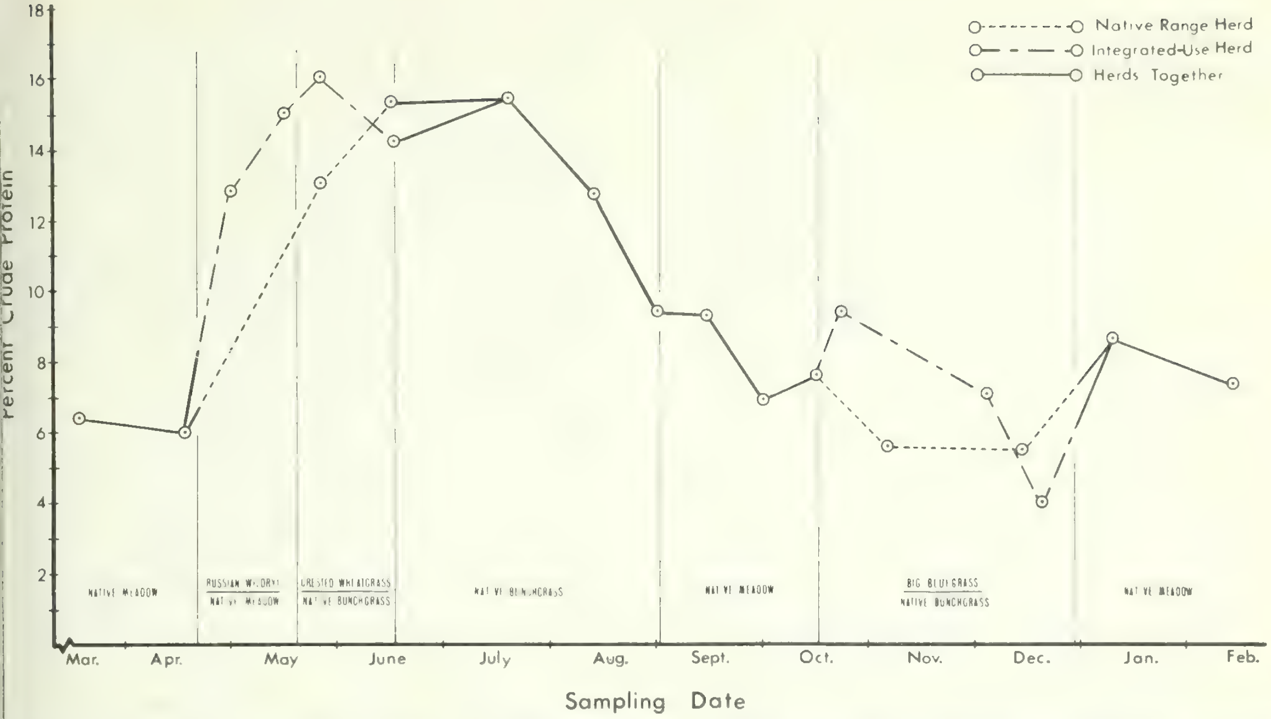


Figure 20.—Schematic comparison of native plus seeded range grazing system with native range only (from Currie 1969b).



igure 21.—Annual trends of dietary crude protein in forage samples collected by fistulated steers (from Malechek 1966).

ribution, encouraging the most efficient stocking ates, and obtaining more uniform use of the forage n ponderosa pine-bunchgrass ranges (Skovlin 1965). hese practices include: Fencing for better livestock ontrol and distribution, development or hauling of ater, adjusting salt grounds to encourage uniform se, range riding, and construction of trails and riveways to move livestock and improve access. One r more of these practices would be appropriate for early all ranges. There is no one standard prescripion, however; problems must be resolved for each pecific range unit, but attention to one or more of hese practices can determine the success or failure f the more complex procedures.

Factors Affecting the Future of Livestock Grazing and Range Research

and Use Patterns and Priorities

In evaluating grazing and other problems of the onderosa pine type, it is essential that we objectively eview current and expected land use priorities. arlier land use problems revolved around such ctivities as mining, developing access roads and ailroads, obtaining adequate timber for construction nd fuel, and growing crops to sustain the expanding opulation. The important grazing problem of those times was locating ranges with the most prolific vegetation, and converting forage into a maximum of beef as quickly, profitably, and close to consumer markets as possible. These uses of the ponderosa pine-bunchgrass type have decreased while other uses have increased in importance. Not enough is known of the impacts of one use upon another — which are compatible, which are not. Future research in the pine country must therefore include multiple uses, to determine how and where grazing fits into the land use pattern.

Most cattle that graze on the National Forest lands of Colorado utilize ponderosa pine-bunchgrass ranges, at least part of the season. Therefore, the following data are closely related to the pine-bunchgrass type: In 1956, 152,887 cattle grazed on Colorado's National Forests, about half the 306,656 that grazed in 1940. Animal months dropped even more — 57.5 percent. Permittees numbered 3,506 in 1940 and 1,847 in 1956, a decrease of about 47 percent. Since 1956, animal numbers have stayed almost the same, but the number of permittees has declined another 25 percent.

Some 30 percent of ponderosa pine bunchgrass ranges, within and adjacent to National Forests of the Front Range, are privately owned. Such land is usually located along streams and on other productive sites. Amount of grazing provided by these holdings is unknown, but the amount of forage produced is undoubtedly as large as that produced on public lands. It appears likely that these private rangelands, occupying the most fertile sites, will continue to be of great importance, but often for uses other than grazing.

Water has been and will continue to be a primary resource in regulating land use activities. Water yield from the ponderosa pine-bunchgrass ranges amounts to 3 to 5 inches annually, about 20 percent of the annual precipitation, or 4 million acre-feet. In contrast, water yield from the higher Continental Divide area amounts to 12 to 18 inches, or about 50 to 70 percent of the annual precipitation. This difference is primarily due to the overwinter snow accumulation before melt starts at the higher elevations. Only on the north exposures does snow accumulate in the ponderosa pine-bunchgrass ranges. On south exposures and in the valley bottoms, winter snows melt soon after a storm.

In 1950, a Forest Service report prepared for the President's Water Resources Policy Commission (USDA FS 1950), in discussing problems in the Missouri River Basin, made these interesting statements: "A major use of water . . . is for irrigation . . . A secondary, but essential use . . . is for livestock . . . The generation of hydro-electric power is becoming a very important use . . . Another important use of water which has not been fully recognized is for recreation . . . the use of water for industrial purposes is rather limited (but) use . . . for this purpose will increase . . . The primary function of these lands . . . is to regulate streamflow and to prevent sedimentation. Most of these lands may be used also for timber production, grazing, and recreation in varying degrees without adversely affecting their watershed protective values."

Recreation, including hunting and fishing, has become the second most important use of National Forests in the upper Arkansas and South Platte watersheds (Reid and Love 1951). In the Rocky Mountain Region (R-2) of the Forest Service, recreational visits increased from slightly over 2 million in 1946, to over 16 million in 1970. Ponderosa pine country flanking the eastern slopes of the central Rockies bore the brunt of this accelerated use, as people from population centers from Laramie to Albuquerque "have gone to the mountains" for recreation.

Complementary to recreation use has been the development of homes in ponderosa pine country. Once classed as summer homes, it was estimated in 1953 that some 800 such homes had been constructed on the public lands of the pine type. Since that time, thousands of homes have been developed on private lands within the type, but they are now usually yearlong residences of people commuting to urban centers. In their leisure time, and as a result of building roads, cutting trees, using water, and other activities, these residents exert a considerable impact on the natural resources. In addition, ponderosa pine lands which were once operational livestock ranches have been sold as real estate developments. Thus, grazing continues to decrease in the pine type.

Estimates of future requirements for wood products indicate it may become necessary to harvest low-quality second-growth timber. Following World War II, harvesting of timber in the ponderosa pine-bunchgrass type steadily declined. Spruce, fir, and lodgepole pine replaced the ponderosa pine because of its lowered quality and small size. Yet, about 9 billion board-feet of timber is available in the pine country, most of it in the form of second-growth trees. Associated with anticipated use of ponderosa pine timber is the demand for Christmas trees. Harvesting these small trees is a useful means of improving the growth of pine and its companion Douglas-fir.

Relating Demands to Resource Capabilities

The important consideration is that total demand upon a constant or diminishing forest resource base continue to mount. Intelligent appraisals of resources and demands will be required to adequately meet the challenge. The primary objective of future natural resource research in the ponderosa pine-bunchgrass type should be to obtain direct solutions to fundamental aspects of problems. The relationship of timber harvest and grazing, for example, to trout production in streams, to production of forage for deer and elk, and to picnicking and camping activities are important questions. More complete knowledge of such relationships will make possible the development and adoption of sound land use practices to derive the maximum total value from grazing, water yield, timber production, and recreational opportunity.

To meet these objectives, more general knowledge of the ponderosa pine-bunchgrass ranges is needed. We need to know the amount and location of merchantable timber and usable grazing lands, the distribution of soil types and their productive and hydrologic characteristics, streamflow and weather characteristics for drainages originating in the pine type, and the motivation, use areas, and demands that campers, picnickers, hunters, and fishermen place on the forest, range, and water resources. This knowledge should encompass the common range of exposures, slopes, soils, and vegetation subtypes found within the pine country.

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COMMON AND SCIENTIFIC NAMES OF PLANTS AND ANIMALS

lants

Grasses and Grasslike

luegrass, Sherman big	*Poa ampla* Merr.
luestem, little	*Andropogon scoparius* Michx.
rome, smooth	*Bromus inermis* Leyss.
ropseed, pine	*Blepharoneuron tricholepis* (Torr.) Nash
escue, Arizona	*Festuca arizonica* Vasey
escue, Idaho	*Festuca idahoensis* Elmer
escue, sheep	*Festuca ovina* L.
escue, Thurber	*Festuca thurberii* Vasey
rama, blue	*Bouteloua gracilis* (H.B.K.) Lag.
airgrasses	*Deschampsia* spp.
inegrass	*Koeleria cristata* (L.) Pers.
luhly, mountain	*Muhlenbergia montana* (Nutt.) Hitchc.
luhly, pullup	*Muhlenbergia filiformis* (Thurb.) Rydb.
luhly, screwleaf	*Muhlenbergia virescens* (H.B.K.) Kunth.
atgrass, Parry	*Danthonia parryi* Scribn.
ushes	*Juncus* spp.
edges	*Carex* spp.
edge, sun	*Carex heliophila* Mackenz.
leepygrass	*Stipa robusta* (Vasey) Scribn.
quirreltail, bottlebrush	*Sitanion hystrix* (Nutt.) J. G. Smith
umblegrass	*Schedonnardus paniculatus* (Nutt.) Trel.
heatgrass, crested	*Agropyron cristatum* (L.) Gaertn.
heatgrass, intermediate	*Agropyron intermedium* (Host) Beauv.
heatgrass, slender	*Agropyron trachycaulum* (Link) Malte
heatgrass, western	*Agropyron smithii* Rydb.
ildrye, Russian	*Elymus junceus* Fisch.

Forbs

Asters	*Aster* spp.
Bluebells	*Mertensia* spp.
Cinquefoils	*Potentilla* spp.
Fleabane, trailing	*Erigeron flagellaris* A. Gray
Geranium, Fremont	*Geranium fremonti* Torr.
Geranium, Parry	*Geranium parryi* Engelm.
Goldaster, hairy	*Chrysopsis villosa* (Pursh.) Nutt.
Goosefoot	*Chenopodium album* L.
Groundsel	*Senecio fendleri* Gray
Loco, Lambert	*Oxytropis lambertii* Pursh
Lupines	*Lupinus* spp.
Milkvetch, purple	*Astragalus striatus* Nutt.
Pussytoes, Rocky Mountain	*Antennaria parvifolia* Nutt.
Sagebrush, fringed	*Artemisia frigida* Willd.
Sweetclover, yellowblossom	*Melilotus officinalis* (L.) Lam.
Yarrow, western	*Achillea lanulosa* Nutt.

Trees and Shrubs

Aspen, quaking	*Populus tremuloides* Michx.
Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Cinquefoil, shrubby	*Potentilla fruticosa* L.
Douglas-fir, Rocky Mountain	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco.
Fir, subalpine	*Abies lasiocarpa* (Hook.) Nutt.
Oak brush	*Quercus* spp.
Pine, lodgepole	*Pinus contorta* Dougl.
Pine, ponderosa	*Pinus ponderosa* Lawson
Rose, Arkansas	*Rosa arkansana* Porter
Spruce, Engelmann	*Picea engelmannii* Parry
Willows	*Salix* spp.

Mammals

A list compiled for the Manitou Experimental Forest[6] is representative for the Eastern Slope pine type. The abbreviated list below includes the common large and small mammals. The Western Slope pine type would have many of the same genera and some of the same species. A few additional animals such as the elk (*Cervus canadensis* Erxleben) in western Colorado and the ring-tailed cat (*Bassariscus astutus* Lichtenstein) in New Mexico would be other more common species to be included.

Lagomorpha

Cottontail, mountain	*Sylvilagus nuttalli*
Jackrabbit, white-tailed	*Lepus townsendi*

Carnivora

Bear, black	*Ursus americanus*
Bobcat	*Lynx rufus*
Coyote	*Canus latrans*
Fox, red	*Vulpes fulva*
Mink	*Mustela vison*
Weasel, long-tailed	*Mustela frenata*

Artiodactyla

Deer, mule	*Odocoileus hemionus*

Insectivora

Shrew, masked	*Sorex cinereus*
Shrew, vagrant	*Sorex vagrans*

Rodentia

Beaver	*Castor canadensis*
Chipmunk, Colorado	*Eutamias quadrivittatus*
Chipmunk, least	*Eutamias minimus*
Gopher, northern pocket	*Thomomys talpoides*
Ground squirrel, golden-mantled	*Spermothilus lateralis*
Ground squirrel, thirteen-lined	*Spermothilus tridecemlineatus*
Marmot, yellow-bellied	*Marmota flaviventris*
Mouse, deer	*Peromyscus maniculatus*
Mouse, western jumping	*Zapus princeps*
Muskrat	*Ondatra zibethicus*
Porcupine	*Erethizon dorsatum*
Prairie dog, white-tailed	*Cynomys gunnisoni*
Squirrel, red	*Tamiasciurus hudsonicus*
Squirrel, tassel-eared	*Sciurus aberti*
Vole, meadow	*Microtus pennsylvanicus*
Vole, long-tailed	*Microtus longicaudus*

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[6] *List prepared by Vincent H. Reid, Wildlife Biologist, Res. Bur. Sport Fish. and Wildl., USDI Fish and Wildl. Serv., Fort Collins, Colo.*

Agriculture—CSU, Ft. Collins

Currie, Pat O.
1975. Grazing management of ponderosa pine-bunchgrass ranges of the central Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-159, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Pine-bunchgrass ranges have historically been important livestock-producing areas in the central Rocky Mountains. Grazing will continue to be important, but in conjunction with other uses of the land. Livestock-management techniques are well developed and soundly based on research within the pine-bunchgrass type. There is a need, however, to understand the interrelationships of other land uses, particularly as they relate to human population pressures. Research needs, as well as what is known, are described for several vegetation cover types. Other resources, such as timber, soil, and water, are evaluated in relation to grazing.

Keywords: Grazing management, pine-bunchgrass type, *Pinus ponderosa.*

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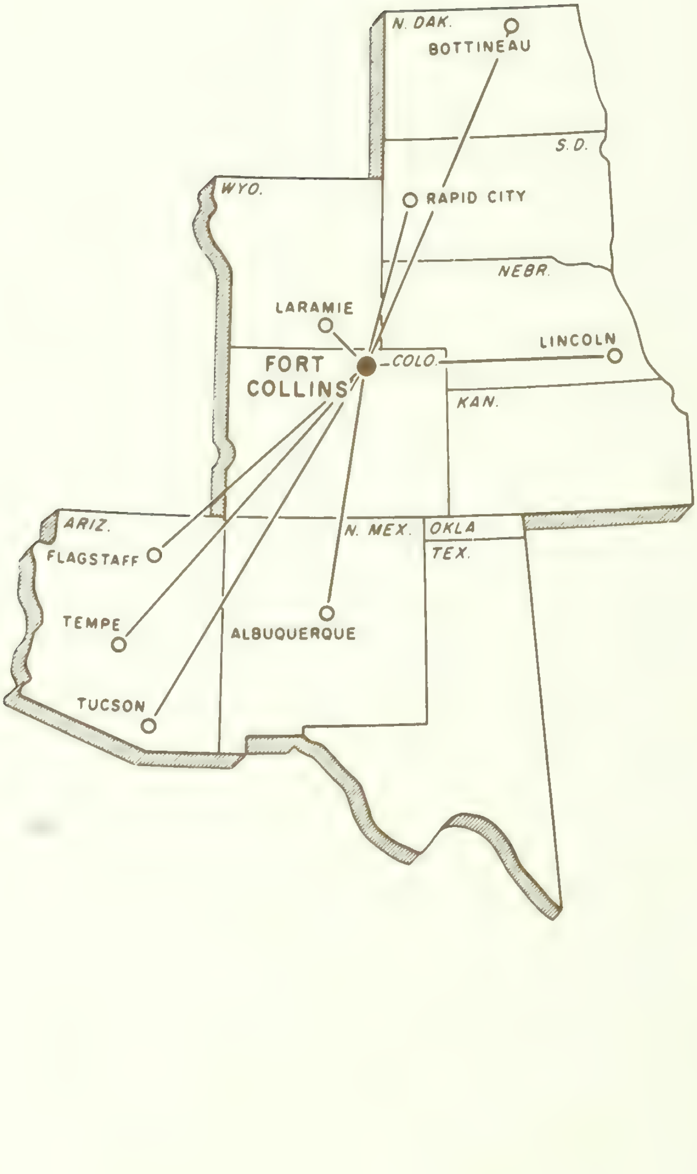
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Rocky Mountain Forest and
Range Experiment Station
Forest Service
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CHARACTERISTICS AND MANAGEMENT OF SOUTHWESTERN PINYON-JUNIPER RANGES:

The Status of Our Knowledge

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H. W. Springfield

Abstract

Springfield, H. W.
1976. Characteristics and management of southwestern pinyon-juniper ranges: The status of our knowledge. USDA For. Serv. Res. Pap. RM-160, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

The pinyon-juniper type, characterized by diversity of climate, soils, and topography, covers about 30 million acres in Arizona and New Mexico. The major problem is widespread deterioration of the range resources due to overgrazing and increases in tree density. General guidelines are available for judging the condition and grazing management of pinyon-juniper ranges, as well as for deciding where and how to control the trees for range and wildlife habitat improvement. Although further research is warranted, information is adequate to modify and manage the type to provide an optimum mix of products. These include forage for livestock, and food and habitat for wild animals as the main products; also included are fireplace wood, fenceposts, pinyon nuts, and Christmas trees.

Keywords: Range management, pinyon-juniper type, forage, tree control, *Pinus* sp., *Juniperus* sp.

USDA Forest Service
Research Paper RM-160

February 1976

CHARACTERISTICS AND MANAGEMENT OF SOUTHWESTERN PINYON-JUNIPER RANGES:

The Status of Our Knowledge

H. W. Springfield, Range Scientist
Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained at Fort Collins in cooperation with Colorado State University; author is located at Albuquerque in cooperation with the University of New Mexico.

Contents

Page

Highlights 1
Physical Characteristics 1
  Climate 3
  Geology and Soils 3
Ecological Characteristics 4
  Communities 4
  Successional Patterns 6
Social and Economic Characteristics 9
  Historical Development 9
  Current Situation 9
  Ranching Operations 9
Grazing Use 10
  Kind of Animals 10
  Carrying Capacity 10
  Seasons of Grazing 10
  Grazing Systems 11
Improving Forage Production 12
  Seeding 12
  Tree Control 14
  Fertilizer Applications 21
Management Considerations 21
  Manipulation of Tree Cover 21
  Guidelines for Grazing Management 22
  Correlating Grazing with Other Uses 23
Conclusions and Recommendations 26
Literature Cited 28
Common and Botanical Names of Plants Mentioned 32

CHARACTERISTICS AND MANAGEMENT OF SOUTHWESTERN PINYON-JUNIPER RANGES:
The Status of Our Knowledge

H. W. Springfield

Highlights

The pinyon-juniper type, characterized by diversity climate, soils, and topography, covers about 30 illion acres in Arizona and New Mexico. It has ovided feed for animals, and wood, nuts, and other oducts for man for centuries. A general problem at overshadows others is widespread deterioration the range resources due to overgrazing and creases in tree density.

General guidelines are available for judging the ndition of pinyon-juniper ranges, as are general iidelines for management. Resting areas from azing during the growing season at 1- to 3-year tervals has been recommended.

The best use of pinyon-juniper in the foreseeable ture is as range for grazing animals. If developed to eir potential, pinyon-juniper ranges undoubtedly uld furnish forage for more animals. The full tential of these ranges is rarely realized.

More information is available relating to the ntrol of pinyon-juniper than to other aspects of anagement. Early attempts at cabling produced ly transitory benefits. Now, with the experience of st failures and successes, reasonably reliable guide- es have been developed. Responses to control also ive been studied in some detail, and situations to be oided have been pointed out. Because these guide- es are readily available, most land managers are miliar with the various methods and the results to expected. Careful attention must be paid to site lection and to characteristics of the tree stands in ciding which method to use.

The benefits of pinyon-juniper control have been ialyzed in economic terms, but further studies are eded. Projects that are less successful than the best ll produce a negative net return. Therefore, consid- able planning and forethought should precede any tempts at pinyon-juniper conversion.

Ecological evidence points to suppression of fire as major factor influencing the spread of juniper in rthern Arizona. It seems logical, therefore, that escribed burning would be a useful tool for convert- g juniper stands to grassland. Its use has been ccessfully demonstrated in certain areas.

A fair amount of information is available concern- g species and methods for seeding pinyon-juniper nges. Research results, however, indicate seeding odland ranges in the Southwest is a risky venture.

The importance of the pinyon-juniper as wildlife bitat is well recognized, mainly for deer, but also r elk, turkey, and other species.

Shrub abundance is a key factor influencing the use of pinyon-juniper ranges by game animals. Recommendations for improving wildlife habitat are to control trees on the more gentle terrain (less than 15 percent slope) and deeper soil, and leave the ridges and steeper slopes untreated, especially the northeast slopes.

Only limited information is available concerning the effects of grazing on runoff and erosion from pinyon-juniper ranges. As a general rule, replacement of pinyon-juniper by grass results in less soil loss but the effects on water yield are negligible.

Coordinating the various land uses holds promise of improving the management of pinyon-juniper in the Southwest. Utilization of wood products is related either directly or indirectly to the production or recovery of the other woodland resources.

In the final analysis, the evidence suggests the pinyon-juniper type in the Southwest can be modified and managed for an optimum mix of products: forage for livestock, and habitat and food for wild animals are the main products; important also are fireplace wood, fenceposts, pinyon nuts, Christmas trees, and esthetically pleasing surroundings—for recreation and living—for people.

Physical Characteristics

The pinyon-juniper type covers about 30 million acres in Arizona and New Mexico (Aldon and Springfield 1973). It is widely distributed over the north half of Arizona, and throughout all except southeast and south-central New Mexico (fig. 1). The type is characterized by pinyon pine,[2] one-seed juniper, and Utah juniper. Blue grama is the most common understory species.

Pinyon-juniper ranges in the Southwest have been grazed by domestic livestock for more than 200 years. For centuries the trees have provided people with fuelwood, posts, poles, and pinyon nuts. Pressures on the resources have been most intense immediately adjacent to the settlements scattered throughout the type, but all pinyon-juniper ranges in the two States, even those rather remote from towns, have had a long history of use.

Although mainly important as range for domestic livestock and habitat for wildlife, pinyon-juniper also has forest, watershed, and recreation values.

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[2] *Common and botanical names of plants mentioned are listed at the end of this Paper.*

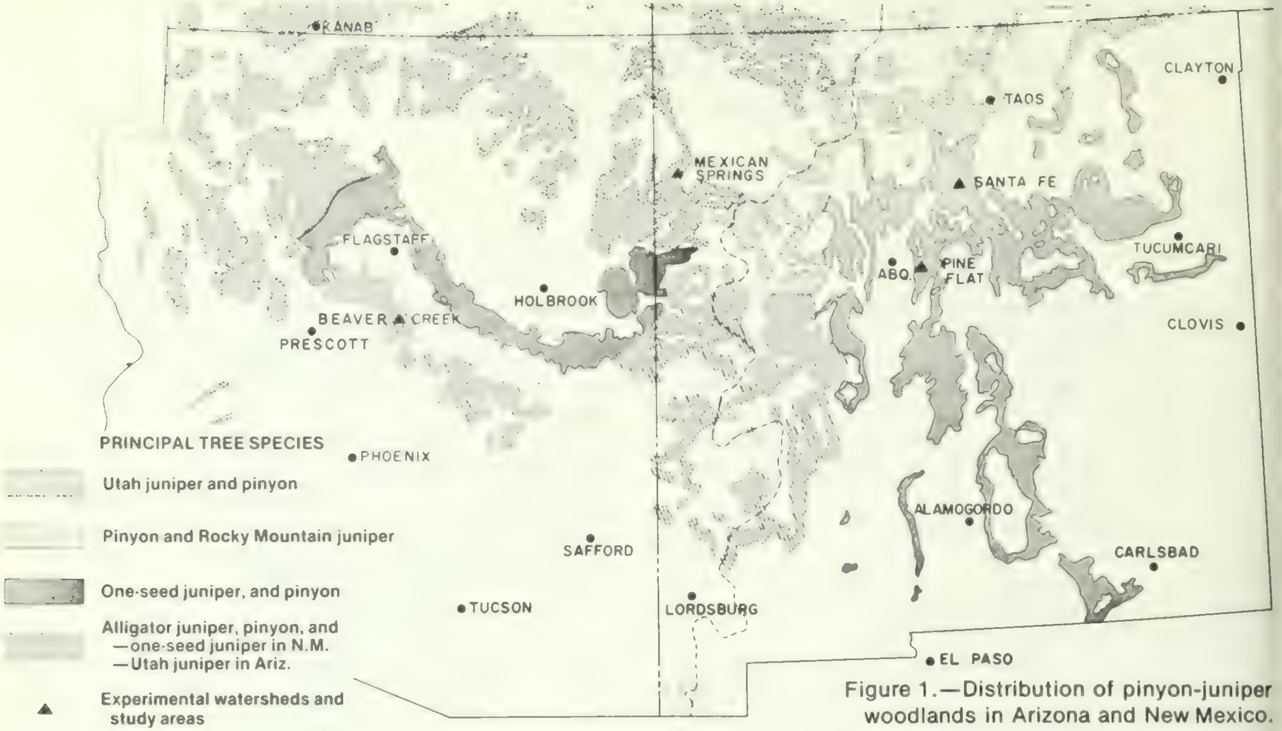

Figure 1.—Distribution of pinyon-juniper woodlands in Arizona and New Mexico.

The pinyon-juniper type generally is found at elevations from 4,500 to 7,500 feet. At the upper limits of its range, the type mixes with Gambel oak and ponderosa pine; at its lower limits it blends with grassland, oak woodland, or desert shrub. Density of the tree stands varies. In a few areas, the trees are so dense that practically no understory exists. Such areas, usually dominated by pinyon, have little if any value for grazing. At the other extreme are areas where the trees—usually junipers—are widely spaced, and the aspect is savanna with a cover of herbaceous or shrubby plants (fig. 2).

Thirty-two percent of the National Forest lands in New Mexico support pinyon-juniper (Aldon and Brown 1971). More than 24 percent of each Forest entirely within the State is in this type; 46 percent of the Cibola is classed as woodland:

National Forest	**Size (USDA-FS 1970)**	**Pinyon-juniper woodland type**	
	(Acres)	*(Acres)*	*(Percent)*
Apache (large portion in Ariz.)	616,328	150,270	24.4
Carson	1,440,919	394,616	27.4
Cibola	1,594,086	732,550	46.0
Coronado (large portion in Ariz.)	69,567	6,744	9.7
Gila	2,702,643	931,164	34.4
Lincoln	1,103,220	269,050	24.4
Santa Fe	1,468,999	358,926	24.4
Total	8,995,762	2,843,320	32.0

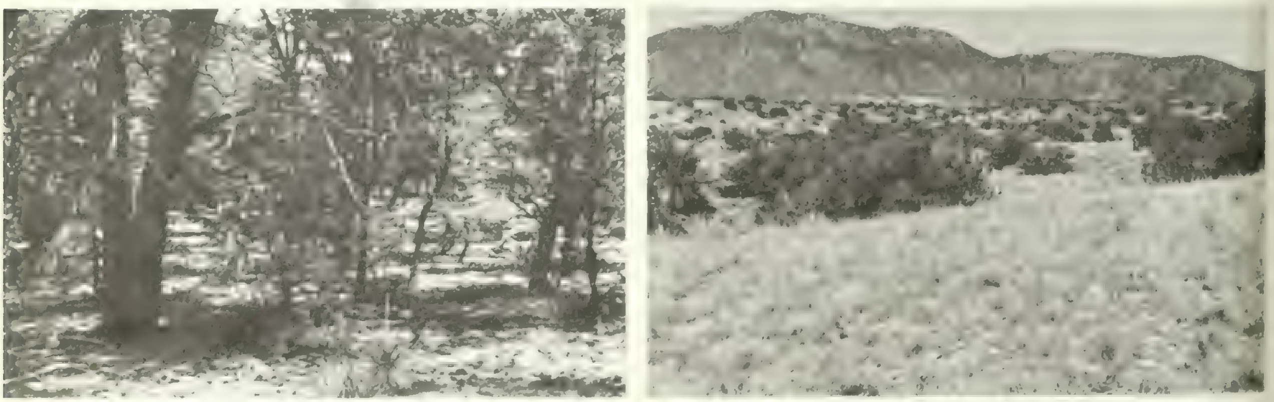

Figure 2.—**Left**, Dense stand of pinyon with practically no herbaceous understory; **Right**, open stand of trees with good grass cover.

Climate

Annual precipitation usually is from 12 to 22 inches. The more open stands receive 12 to 14 inches, whereas the denser stands may receive 16 to 22 inches of rain and snow. Seasonal distribution varies; for example, in eastern New Mexico 75 percent of the year's precipitation falls during the growing season (April through September) compared with only 45 percent in western Arizona.

Winter storms come mainly from the Pacific and move eastward. As these storms move inland they drop most of their moisture on the mountains of central Arizona. The most prominent feature is the Mogollon Rim, which has wet winter climate on the windward side and a dry winter climate on the lee side (Jameson 1969). These California storms have lost much of their moisture by the time they reach New Mexico.

Summer storms originate from the Gulf of Mexico and travel northwest across New Mexico into Arizona. The effect of this summer monsoon decreases toward the northern part of the two States. Because much of the summer rain falls as a result of convectional storms, the higher elevations receive the higher rainfall.

Differences in precipitation patterns are reflected in the vegetation. Eastern New Mexico gets the bulk of its precipitation during warm weather, and the vegetation is typically Great Plains grassland. The various grassland communities form broad ecotones with pinyon-juniper woodland. At the other extreme in northern Arizona, much of the precipitation comes from cold winter storms and the vegetation shows affinities to the Great Basin.

The proportion of winter-to-summer precipitation varies according to local topography and elevation, as well as geographic location. Lavin originally classified the climate of the pinyon-juniper type in 1953 (USDA-FS 1953, p. 12-14). His classification, slightly revised in 1964 (personal communication), is as follows:

Climate	Winter	Precipitation Summer (*Inches*)	Total
Cool, moist	9-11	7- 9	16-20
Warm, moist	10-13	6- 9	16-22
Cool, winter dry	5- 7	7- 9	12-16
Warm, winter dry	4- 7	8-11	12-18
Cold, winter dry	4- 6	8-10	12-16
Cold, summer dry	7- 9	4- 6	11-15
Warm, summer dry	7- 9	4- 6	11-15

This classification has been helpful in delineating various pinyon-juniper subtypes and zones for revegetation.

Snow rarely reaches great depth in the pinyon-juniper except at the higher elevations and in the northern parts of the two States. Moreover, the snow usually melts in a few days, especially on south-facing slopes. Only in exceptional winters, perhaps once in 10 years, do the depth and persistence of snow on pinyon-juniper ranges cause problems for ranchers.

Geology and Soils

Pinyon-juniper is found on a wide variety of soils and parent materials. Within the National Forests of Arizona and New Mexico, soils supporting pinyon-juniper vary in texture from stony, cobbly, and gravelly sandy loams to clay loam and clay, and in depth from shallow to deep. Parent materials likewise vary widely from granite, basalt, limestone, and sandstone to mixed alluvium.

Volcanic parent material is common throughout the pinyon-juniper woodland of both States. From these materials, the Cabezon, Gem, and Springerville soils have formed. Limestones are relatively more abundant in Arizona than in New Mexico. Some of the more common limestone-derived soils are La Porta, Purner, Tortugas, and Winona.

About 32 percent of the pinyon-juniper of Arizona is on soils formed from basalt, much of which has developed into Gem (Thunderbird) and Springerville soils (Jameson and Dodd 1969). An area of similar size (29 percent) is underlain by Kaibab and Redwall limestones, much of which in turn developed into Tortugas and Winona soils. Soil characteristics for various geologic parent materials are as follows:[3]

Parent material	Infiltration capacity	Moisture-holding capacity	Fertility
Jurassic sandstones	High	Low	Low
Supai sandstones	Medium	Medium	Low
Coconino sandstones	High	Low	Low
Kaibab limestone	High	Low	Low
Redwall limestone	Medium	Medium	Medium
Triassic shales	Low	High	Low
Mesa Verde formation	Medium	Medium	Medium
Tertiary volcanics (basalt)	Medium	High	High
Quaternary volcanics	Medium to high	Low to high	Low to high
Granite	High	Low	Low
Sand and gravel	High	Low	Low

Nearly a third of the pinyon-juniper ranges within the National Forests of New Mexico are on highly unstable geologic formations (Aldon and Brown 1971). Sedimentary units make up 54 percent of the acreage, igneous units 39 percent, and Precambrian igneous and metamorphic formations 7 percent. The Datil formation, a high sediment producer, makes up 27 percent of the Cibola woodland and 42 percent of the Gila woodland.

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[3] *Jameson, Donald A. 1967. Productive potential of sites in the pinyon-juniper type. (Establishment and progress report on file at Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.)*

Jameson[3] listed herbage production potentials for various soils in northern Arizona as follows:

Parent material	Soil series	Production potential (*Lb/acre*)
Basalt	Thunderbird	1,200-1,400
Kaibab limestone	Crater:	
	shallow	1,000-1,200
	very shallow	600- 800
Moenkopi shale	Tours	1,200-1,500
	Moenkopi	500- 800
Chinle shale	Chinle	500- 800

Herbage production on Springerville soils was similar to that on Gem (Thunderbird) and Tortugas soils when there were few trees (Jameson and Dodd 1969), but the Springerville soils produce much less perennial vegetation than the other soils when there is appreciable tree cover.

Ecological Characteristics

Communities

Several pinyon-juniper communities or subtypes have been recognized (see fig. 1). Pinyon is proportionately more abundant than junipers at the higher elevations and in the northern portions of Arizona and New Mexico (fig. 3). Pinyon is replaced by Mexican pinyon in extreme southern New Mexico and southwestern Arizona, and by singleleaf pinyon in extreme northwestern Arizona.

Throughout most of the type, junipers outnumber pinyons. One-seed juniper is widely distributed in New Mexico, but virtually absent from northeastern and northwestern Arizona. Just north of the Mogollon Rim it forms a belt in mixture with pinyon. South of the Mogollon Rim, the dominant species at the higher elevations is alligator juniper, which is common in southern and western New Mexico. Utah juniper is widespread in Arizona, but occurs only in the northwestern part of New Mexico. Rocky Mountain juniper is common in northern New Mexico at elevations above 6,000 feet.

Utah juniper is the dominant species in three of four subtypes recognized in northern Arizona and New Mexico (west of the Continental Divide) by Jameson[3] (table 1). According to Jameson, high-producing areas are in the higher elevations of the warm moist zone, where grasses such as sideoats grama and bottlebrush squirreltail are common. Low-producing areas are in the cool, winter-dry zone characterized mainly by blue grama.

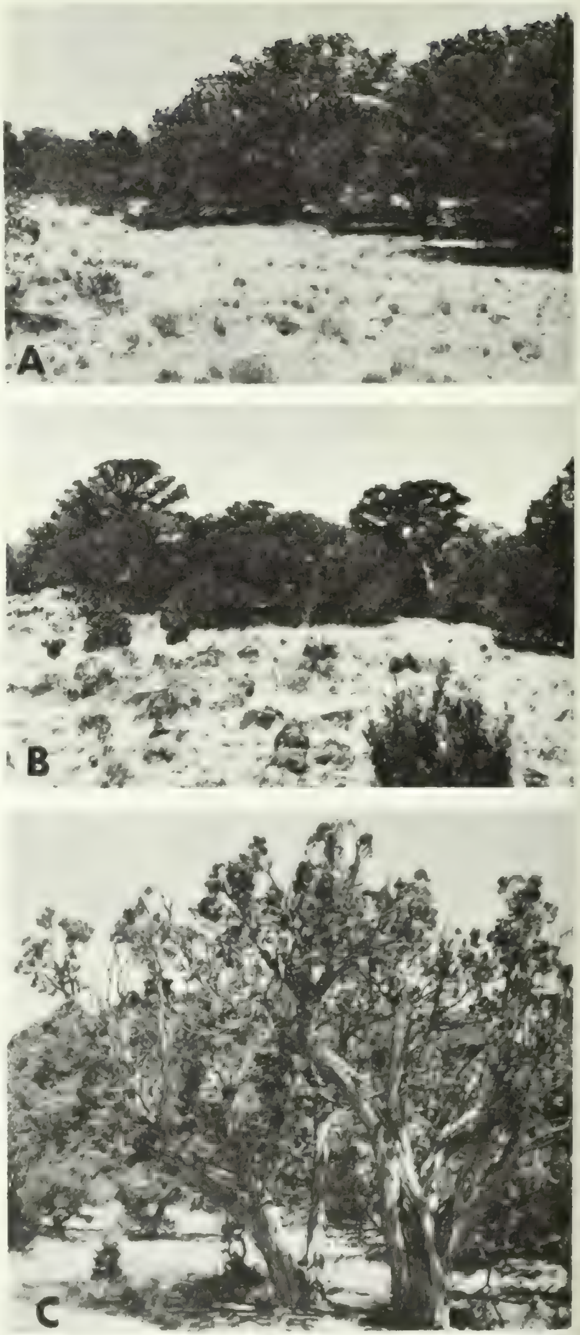

Figure 3.—The occurrence of pinyon and the junipers ranges from relative dense, pure stands of pinyon **(A)**, to intermixtures of the species **(B)**. At lower elevations, Utah juniper forms extensive open stands **(C)**. Alligator juniper occurs in both the pinyon-juniper type and throughout the lower pine type (from Barger and Ffolliott 1972).

Ecological studies of 71 pinyon-juniper sites in northern Arizona and northwestern New Mexico showed the following principal species (Daniel et al. 1966):

Table 1.--Description of four subtypes in pinyon-juniper woodland in northern Arizona and New Mexico (west of the Continental Divide) as recognized by Jameson[1]

Subtype	Climate	Soils	Understory	Acreage	
				Arizona	New Mexico
				Acres	
1. Utah juniper-pinyon-sagebrush	Cold or warm, dry summer	Sandstones in cooler areas; limestone, basalt or granite in warmer areas	Indian ricegrass	6,636,000	3,082,000
2. Utah juniper-pinyon-sagebrush-muttongrass	Cool, moist	Kaibab limestone, basalt	Cliffrose, muttongrass		
3. Utah juniper-pinyon-alligator juniper-chaparral	Warm, moist	Sandstones, redwall limestone, granite, basalt	Sideoats grama, squirreltail, western wheatgrass, black dropseed, Junegrass	5,006,000	0
4. One-seed juniper-pinyon-blue grama	Cool, dry winter	Kaibab limestone, tertiary sands and gravels, basalt	Blue grama, galleta, western wheatgrass	2,258,000	1,465,000

[1] Jameson, Donald A. 1967. Productive potential of sites in the pinyon-juniper type. (Establishment and progress report on file at Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.)

	Percent of composition
Overstory	
Utah juniper	43.8
Pinyon	37.0
One-seed juniper	9.3
Understory	
Blue grama	42.2
Snakeweed	9.8
Big sagebrush	4.8
Galleta	4.6
Squirreltail	3.5
Black sage	2.6
Indian ricegrass	1.5
Muttongrass	1.5

In these same studies, classification of pinyon-juniper sites showed site quality was influenced mainly by soil depth, profile development, and total precipitation.

In the foothills at elevations of 6,500 to 7,500 feet near Fort Stanton in southern New Mexico, one-seed juniper is several times more abundant than pinyon (Pieper et al. 1971). Blue grama constitutes 55 to 80 percent of the understory. Herbage production during a 6-year period averaged from 612 to 1,405 pounds per acre, depending on site conditions. Production was higher on loamy sites than on hill sites.

Phytosociological studies along the eastern edge of the type in New Mexico reveal how stand composition varies with elevation and latitude (Woodin and Lindsey 1954). Pinyon increases while juniper decreases with increasing elevation (fig. 4). Pinyon and juniper

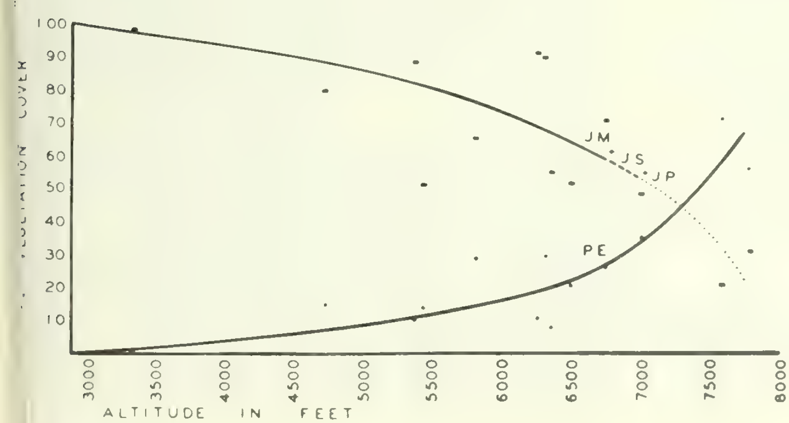

Figure 4.—Percentage of pinyon and juniper at different elevations (from Woodin and Lindsey 1954). PE = pinyon; JM = one-seed juniper; JS = Rocky Mountain juniper; JP = alligator juniper.

are about equal at 7,200 feet. The type grades into ponderosa pine at about 7,500 feet.

Three geographical subdivisions are recognized (fig. 5). In the northern subdivision, pinyon is more abundant than juniper, whereas juniper is prevalent in the other subdivisions. At a typical site in the central subdivision, one-seed juniper is about twice as abundant as pinyon. The southern subdivision includes southeastern New Mexico, where Mexican pinyon and Texas juniper are represented.

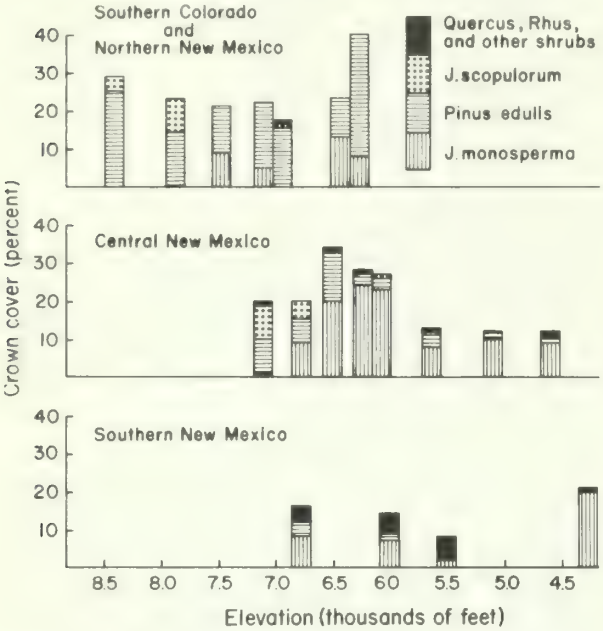

Figure 5.—Tree and shrub cover at 19 woodland sites in New Mexico and southern Colorado (adapted from Woodin and Lindsey 1954).

Pinyon-juniper occurs at elevations from 6,800 to 9,000 feet in the San Augustin Plains (Potter 1957). Pinyon makes up 60 percent of the tree overstory, alligator juniper 30 percent, and one-seed juniper only 2 percent. Gray oak comprises 6 percent of the foliar cover. The two dominants—pinyon and alligator juniper—make up 84 percent of the density, 90 percent of the foliar cover, and 89 percent of the basal area. The understory vegetation is relatively low in cover but high in number of species. Of the seven most important understory species, six are common in the grasslands of the Plains. Blue grama is most important; it alone comprises nearly half of the herbaceous cover. Ragleaf goosefoot is second and is abundant mainly under the shade of the trees. The second most abundant grass is sand dropseed.

Successional Patterns

The most notable successional trend has been the invasion of grassland communities by junipers (fig. 6). Prior to settlement of the Southwest, pinyon-juniper stands were more open and confined largely to the rocky ridges and shallow soils. With the introduction of domestic livestock, many ranges were overgrazed. Grass stands were weakened to the extent they afforded little or no competition to invading tree seedlings. Moreover, the grass was no longer thick enough to carry fire, which had periodically swept across the ranges and killed many trees. Due to the combination of overgrazing and absence of fires, trees not only encroached on the grasslands, but the original stands of trees also became more dense (Parker 1945). Another factor related to the increase in the number of trees was the dissemination of seeds by animals, including birds, coyotes, deer, and domestic livestock. Juniper seeds from animal droppings germinate faster (Johnsen 1962).

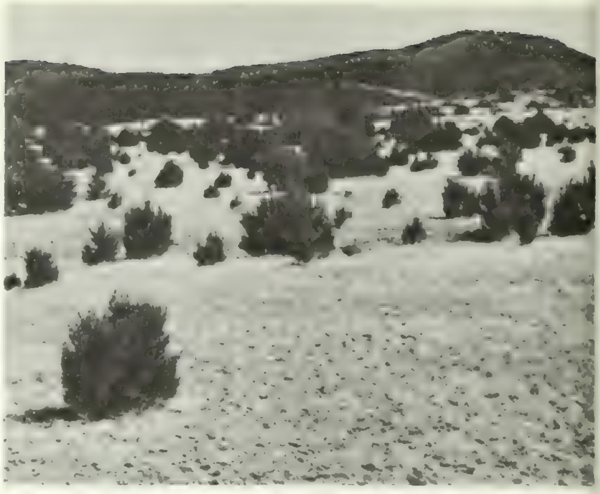

Figure 6.—Invasion of blue grama grassland by small one-seed junipers, near Ruidoso, New Mexico. Invasion of grassland communities by junipers has been a notable successional trend.

Once they become established on an area, trees usually take over as dominants. Because of their height and longevity, trees have advantages over understory plants. Trees are especially favored on coarse-textured soils.

An individual tree influences species composition and growth of understory plants far beyond its canopy. Tree roots provide more competition in the openings than under the tree crowns (Arnold 1964). The surface soil in the openings among dense stands of trees may be nearly filled with tree roots (Plummer 1958).

In general, bunchgrasses seem to be less influenced by the tree crowns than sodformers. Muttongrass and little ricegrass are commonly found under the trees, whereas blue grama grows mainly in the openings. Species such as western wheatgrass, squirreltail, and snakeweed often grow around the outside edge of tree crowns. On the Coconino National Forest, production of early-spring grasses, including muttongrass, squirreltail, prairie Junegrass, and western wheatgrass, was found to be four to five times higher under the crowns of large alligator junipers than for areas of similar size away from the trees (Clary and Morrison 1973). Moreover, grazing animals utilized green forage during the spring season almost entirely under the juniper crowns.

Responses of the herbaceous vegetation to grazing varies according to species, density of the tree stand, elevation, precipitation, soil texture and depth, and other factors. Mid-grasses, particularly sideoats grama, generally increase under protection, whereas they decrease under grazing. Grazing tends to favor short-grasses, prostrate species, and annuals at the expense of palatable shrubs and mid-grasses (fig. 7). A dense tree overstory may prevent any sizable changes in the understory. In New Mexico, during 10 to 14 years of protection from grazing, changes in the herbaceous cover were negligible where the tree canopy exceeded 30 percent, whereas density and production of desirable perennial grasses improved substantially where tree cover was less than 20 percent.[4] On the Fort Stanton range in southern New Mexico, both herbage production and height of blue grama were significantly higher after 12 years' protection from grazing (Pieper 1968). In other studies in New Mexico, total grass cover increased consistently on six representative woodland sites protected from grazing 25 years (Potter and Krenetsky 1967). Under grazing at these six sites, Junegrass decreased or disappeared while tree and forb cover increased.

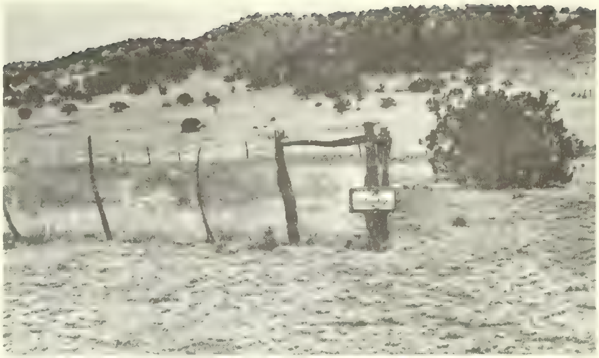

Figure 7.—On many woodland ranges, mid-grasses and palatable shrubs such as fourwing saltbush (still present within the exclosure) have practically disappeared due to continuous, yearlong, heavy grazing.

Perennial understory vegetation generally is greatest where there are few trees. The decrease in perennial grasses and forbs usually is proportional to the increase in overstory pinyons and junipers. In northern Arizona (Arnold et al. 1964), mid- and short-grasses declined sharply as tree overstory increased (fig. 8). Half-shrubs such as broom snakeweed also decreased, especially where the canopy exceeded 25 percent. The effect of tree overstory on the taller shrubs, including cliffrose and algerita, was not pronounced except where the tree canopy was more than 60 percent.

The northern Arizona studies showed an inverse relationship between tree canopy and herbage production (fig. 9). Production was about 600 pounds

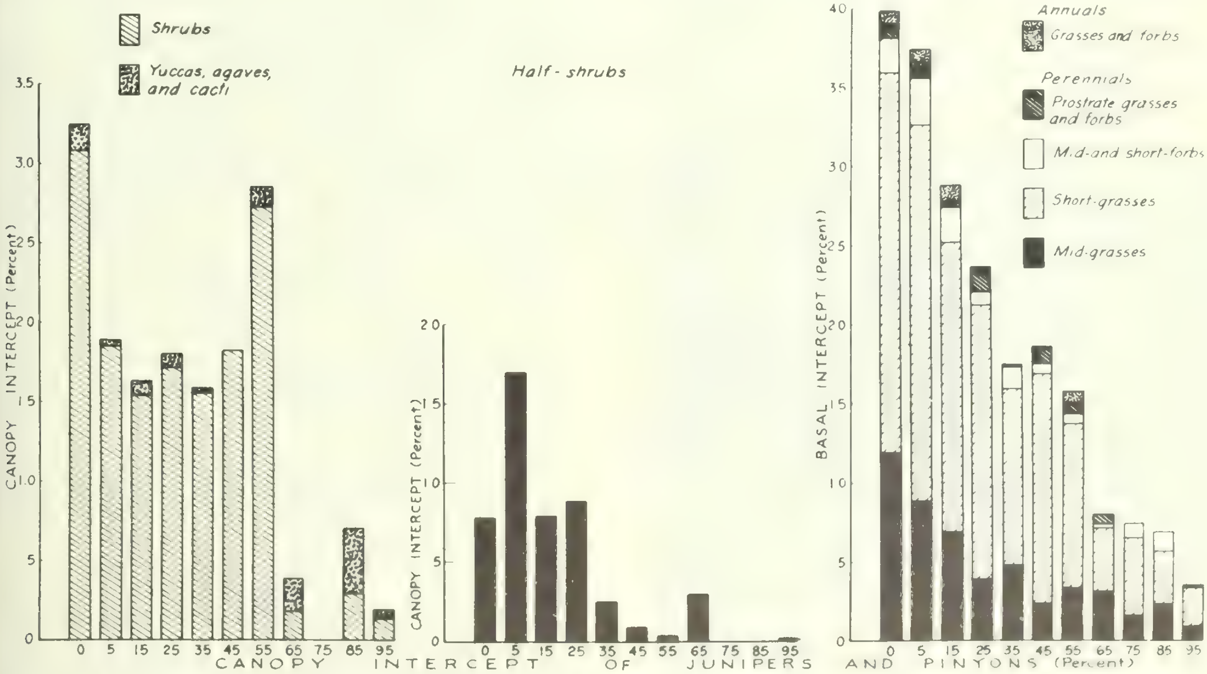

Figure 8.—Relation of understory species to canopy intercept of juniper and pinyon trees in northern Arizona (from Arnold et al. 1964).

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[4] *Springfield, H. W. 1959. Exploratory studies relating to range conditions in the pinyon-juniper zone of the Rio Grande Basin in New Mexico. 21 p. (Unpublished report on file at Rocky Mt. For. and Range Exp. Stn., Albuquerque, N.M.)*

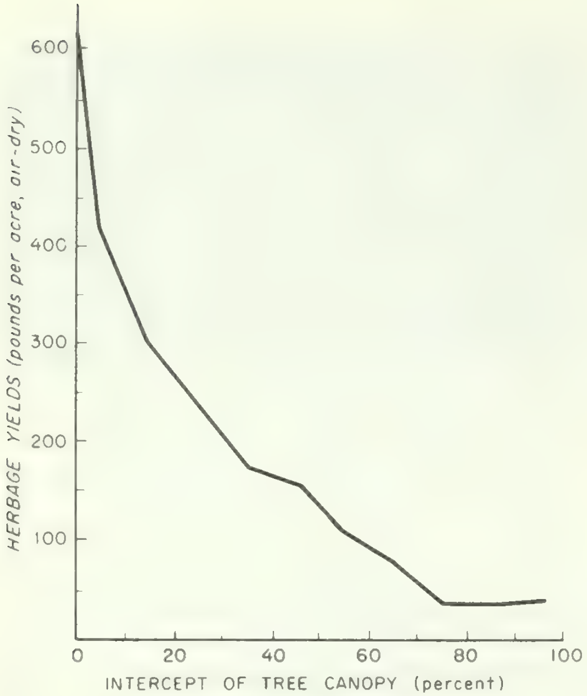

Figure 9.—Relation of air-dry herbage yield to percent canopy intercept of overstory pinyon and juniper in northern Arizona (from Arnold et al. 1964).

per acre with no trees, 300 pounds per acre with 20 percent tree canopy, and less than 50 pounds per acre with an 80 percent canopy.

Tree overstory was categorized in three patterns near Flagstaff: (1) single trees, (2) groups of two or more about the same size, and (3) small trees growing as an understory to larger trees (Jameson 1965a). The large trees apparently were more important as shade for tree seedlings than as a seed source.

Understory vegetation is commonly suppressed by juniper trees, particularly on heavy clay soils (fig. 10). Juniper trees will intercept as much as 40 percent of the precipitation that falls on the crown (Skau 1964a) and up to 80 percent of the direct sunlight (Jameson 1966c). Tree litter and tree root competition, however, appear to be the main factors involved in the reduction of blue grama stands by juniper (Jameson 1966c, 1970). A foliage extract of Utah juniper significantly decreased the germination of blue grama and sideoats grama (Lavin et al. 1968). Half-shrubs such as broom snakeweed and Cooper actinea also were found to suppress blue grama (Jameson 1966a). These two shrubs did not suppress the growth of squirreltail; neither did squirreltail appear to compete against blue grama.

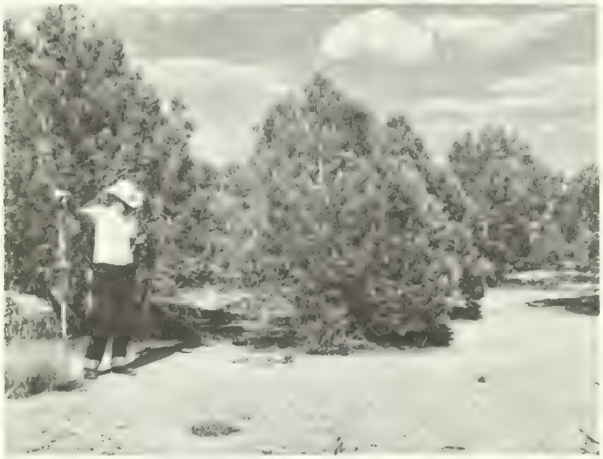

Figure 10.—Dense young stands of Utah juniper that became established about 1900. Trees so dominate the site that understory grasses occur only in isolated patches (from Arnold et al. 1964).

Fire is a natural ecological factor that slows the invasion of junipers and pinyons, and converts old tree stands to grassland (Leopold 1924, Humphrey 1950). Studies by Arnold et al. (1964) indicate successional recovery after fire in dense stands of pinyon-juniper begins with the establishment of annuals (fig. 11). The annual stage peaks in the second and third years. Perennials are more abundant than annuals by the fourth year. Half-shrubs become important the fourth year and continue to increase into the sixth year. From this point, successional recovery takes one of two courses. A perennial shrub stage likely will develop if shrubs such as sagebrush or rabbitbrush are present. Without shrubs, perennial forb-grass may be converted to grassland by second fire. When protected from recurring fires, both the shrub and

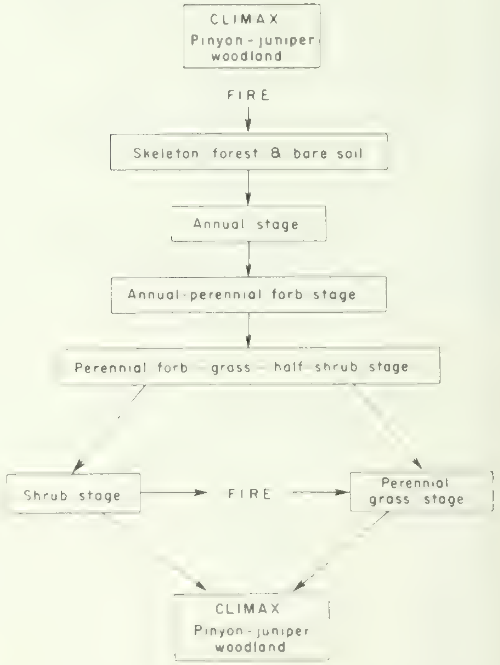
CLIMAX
Pinyon - juniper woodland
FIRE
Skeleton forest & bare soil
Annual stage
Annual-perennial forb stage
Perennial forb - grass - half shrub stage
Shrub stage
FIRE
Perennial grass stage
CLIMAX
Pinyon - juniper woodland

Figure 11.—Possible stages of succession after a fire in northern Arizona (from Arnold et al. 1964).

perennial grass stages will be replaced eventually by climax pinyon-juniper. This successional timetable does not apply to Springerville soils (Warren P. Clary, personal communication).

Fire killed all juniper trees less than 4 feet tall on the Fort Stanton range (Dwyer and Pieper 1967). Altogether, about 24 percent of the junipers and 13.5 percent of the pinyons were killed. Production of blue grama was reduced by 30 percent the year of the fire, but recovery was complete by the next year. Species composition of the herbaceous understory was not affected, although litter was significantly less on burned areas for 3 years after the fire.

Social and Economic Characteristics

Historical Development

The pinyon-juniper type has been used by man for probably 20,000 years; it first served the Indians, then the Spanish, who founded their first settlements in and near the woodland four centuries ago (Randles 1949). Explorations have revealed that many of the early Indian habitations were in the woodland, because of the agreeable climate, plentiful supply of wood for cooking, heating, and building, berries and nuts for food, and perhaps because it was a habitat for turkey, deer, and other wild animals.

The Spanish followed essentially the same pattern of use. Besides depending on junipers and pinyons for fuel and building material, they used the trees for posts in fencing their livestock. Rural Southwesterners always have had a high opinion of the pinyon-juniper type; the pinyon is their traditional Christmas tree, pinyon and juniper foliage is used for decorations on special occasions, and the wood has been everyone's favorite. Burros loaded with packs of wood remained a familiar sight until recently.

As the population of the two States increased during the last 100 years, greater demands were made on the type for more juniper posts to use in fencing domestic animals, and more fuelwood to meet the needs of urban as well as rural people.

Throughout the past 400 years livestock have been grazed, mostly yearlong on an extensive basis. The original Spanish land grants included large blocks of land conducive to extensive management. During recent times, land ownership has become more diverse. This, together with fencing, water development, and homesteading, has resulted in more intensive management of woodland ranges.

Current Situation

Pinyon-juniper ranges continue to be used as in the past, except that demands on the resources have intensified. Grazing still is an important use, and the type remains valuable as wildlife habitat. But these important uses must now be balanced against many others. The type, for example, is receiving much heavier recreational use than formerly.

More and more people are discovering pinyon-juniper woodlands as a desirable place to live. Real pressures are being put on the type by land developers. Roads are being carved through the wooded hills with little regard for plants and soils. Subdivisions are springing up throughout the type.

Changing the use from grazing or wildlife habitat to home or recreational sites is having serious impacts on the land resources and domestic and wild animals. Much former rangeland no longer is available for grazing. Moreover, wildlife food and cover are lost as roads and homes are built. The trend, however, is practically irreversible.

Ranching Operations

Most ranches that use pinyon-juniper ranges are cow-calf outfits. A few ranches have switched largely to yearlings, which often are grazed on leased lands. Not many woodland ranges are grazed by sheep, and goats are nearly nonexistent.

Grazing usually is yearlong unless ranchers have grazing permits, which are seasonal. Many ranchers are practicing rotation or deferred grazing. A few ranchers have irrigated or special nonirrigated pastures, but most depend almost entirely on native range forage.

Supplemental feeding is a common practice. Ranchers supply protein concentrate blocks or cottonseed meal during the winter, or during drought periods.

Herefords are the most popular breed, but there are also Angus, Brangus, and Charolais cattle. Crossbreeding is becoming more popular. Mexican cattle are common on yearling ranches.

Calves and yearlings are the principal source of income. Most calves are dropped in the spring and marketed in the fall, mainly to feedlots.

Seasonal breeding is practiced. Bulls are placed in service as 2-year-olds. They usually are fed supplements prior to being placed in the breeding herd during the summer.

In the central mountainous region of New Mexico, Gray (1970a) reported 32 percent of the grazing use for small (98 head) cow-calf ranches was supplied by USDI Bureau of Land Management (BLM), and USDA Forest Service permits. Only 22 percent of the total grazing use for medium-sized (283 head) ranches was supplied by these two agencies. Investments for a small cattle ranch in central and northwestern New Mexico totaled $120,000 in 1965, compared with $278,000 for a medium-sized ranch. Land organization and investment per ranch in 1965 in small- and medium-sized cow-calf ranches in the central and northwestern mountains of New Mexico (adapted from Gray 1970a, 1970b) were:

	Ranch size	
	Small	Medium
LAND USE		
Rangeland (*acres*)		
Owned	1,720	6,000
Private lease	720	840
State lease	0	640
Total	2,440	7,480
Federal grazing permits (*animal unit months, AUM*)		
Bureau of Land Management	510	520
Forest Service	60	470
Total	570	990
INVESTMENT (*dollars*)		
Owned land	64,000	176,000
Grazing permit (at $25/AUM)	14,000	25,000
Improvements	20,000	29,000
Machinery, equipment	6,000	8,000
Livestock	16,000	40,000
Total	120,000	278,000

Grazing Use

Kind of Animals

Many more cattle than sheep graze pinyon-juniper ranges in the Southwest. Sheep numbers have declined drastically since World War II. Permitted livestock use in 1972 on the woodland ranges of the National Forests in the Southwestern Region of USDA Forest Service was as follows:

	Animals	Grazing use
	(*Number*)	(*AUM*)
Cattle	54,700	630,000
Sheep	15,100	140,000

Few examples can be found of common or dual use of woodland ranges by cattle and sheep. There appear to be opportunities, however, for common use as a means of improving efficiency of forage utilization, particularly on ranges that support a high proportion of forbs and half-shrubs.

Carrying Capacity

Capacities vary considerably, depending on density of the tree overstory, topography, condition of the understory, and many other factors (fig. 12). Range condition, as an expression of "state of health" of the range, usually provides clues as to the number of animals an area will support. Based on an analysis of National Forest Allotments where pinyon-juniper comprises at least 67 percent of the total plant cover, range conditions in 1972 were as follows:

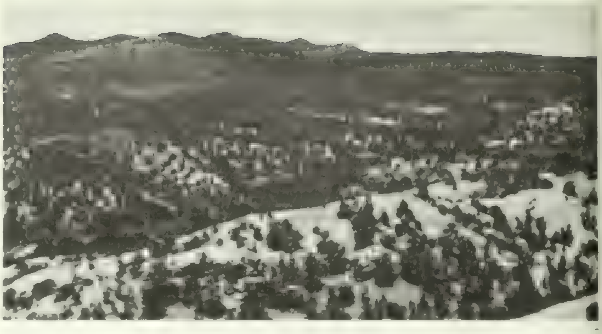

Figure 12.—Grazing capacities of woodland like this in northern New Mexico are low because of the relatively rough topography, shallow soil, sparseness of forage, and scarcity of water for livestock.

Range condition	Area	Grazing capacity
	(*Percent*)	(*Acres/AUM*)
Very poor	5.1	28.2
Poor	40.7	11.8
Fair	46.1	6.6
Good	8.1	3.9

These figures suggest that over 90 percent of the woodland ranges are in poor or fair condition, and that less than 10 percent are in good condition. Pinyon-juniper ranges generally are in better condition on the Coronado, Lincoln, and Tonto National Forests than on the others (table 2).

About twice as many acres are required to support a cow for 1 month on woodland range in poor condition as in fair condition (table 2). Differences in grazing capacities reflect not only differences in range conditions, but also fairly large differences in the plant communities themselves and in environmental conditions from one part of the Southwest to another (figs. 13, 14). For example, the grazing capacity of poor-condition woodland range varies from 16.9 acres/AUM on the Kaibab National Forest to 6.1 acres/AUM on the Lincoln.

Seasons of Grazing

Most pinyon-juniper ranges in Arizona and New Mexico are grazed yearlong, especially lands in private ownership. Because of the generally mild winters and relatively cool summers, the woodland type is well suited to yearlong use. But from the standpoint of conserving the plant and soil resources, some form of seasonal use—in conjunction with deferred grazing—usually is desirable.

About half of the total woodland acreage on National Forest Allotments in the Southwestern Region is grazed yearlong (table 3). About a fifth of the pinyon-juniper woodland is grazed only during summer (May 1 to October 31), or only in the winter (November 1 to April 30). The remaining woodland range is grazed either in the spring or fall, or both.

Table 2.--Range-condition class and estimated grazing capacities on pinyon-juniper ranges on southwestern National Forests

National Forest	Range condition class[1]							
	Very poor		Poor		Fair		Good	
	Percent	*Acres/AUM*	*Percent*	*Acres/AUM*	*Percent*	*Acres/AUM*	*Percent*	*Acres/AUM*
Apache[2]	6	--	42	9.5	42	5.4	10	4.5
Carson	25	19.5	66	14.6	9	--	0	--
Cibola	4	23.6	43	11.1	48	5.5	5	--
Coconino	8	29.2	60	10.8	31	9.0	1	--
Coronado	0	--	9	10.9	71	3.8	20	3.0
Gila	4	--	34	10.2	55	8.1	6	3.9
Kaibab	7	43.8	72	16.9	21	5.9	0	--
Lincoln	1	--	26	6.1	52	5.8	21	4.1
Prescott	3	--	66	9.5	30	5.5	1	--
Sitgreaves[2]	2	--	36	15.0	62	11.3	0	--
Tonto	0	25.0	12	15.0	71	5.9	17	4.1
Santa Fe	1	--	24	--	61	--	14	--

[1] For National Forest Allotments with at least 67 percent pinyon-juniper.
[2] These two Forests were combined subsequent to this statistical summary.

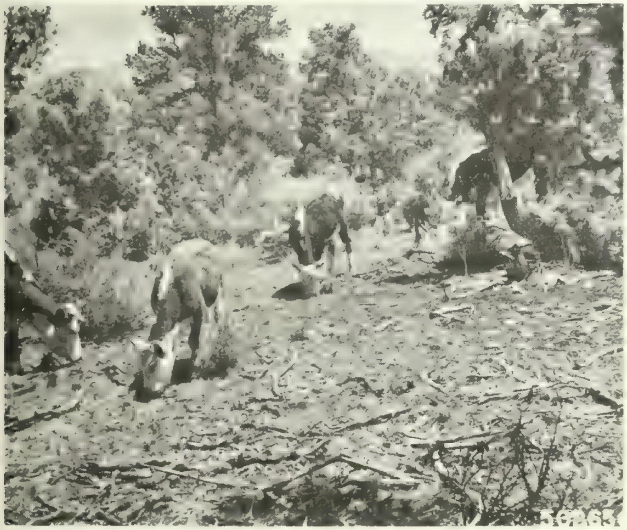

Figure 13.—This very poor-condition range in a moderately dense woodland in northern New Mexico has a grazing capacity of about 20 acres per animal unit month.

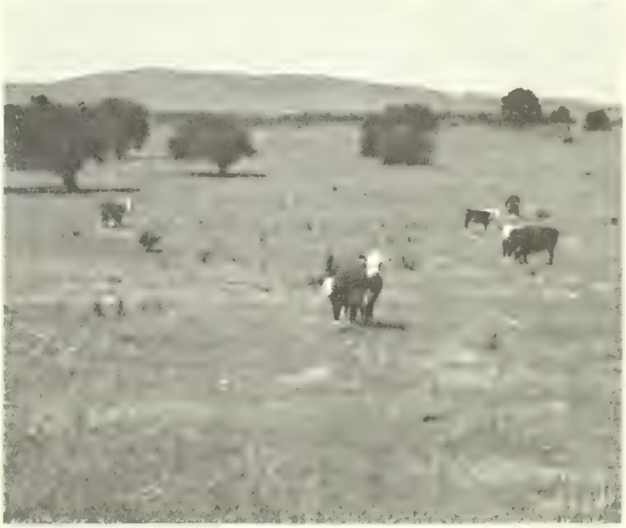

Figure 14.—An example of well-managed pinyon-juniper range. The tree stand is open, and the grassland is in good condition, with a grazing capacity of about 4 acres per animal unit month.

In general, yearlong use of woodland ranges is more prevalent in the central and southern parts of the two States. For example, on 5 of the 12 National Forests in the Southwestern Region—the Apache, Gila, Lincoln, Prescott, and Tonto—90 percent or more of the woodland range is grazed yearlong. By contrast, yearlong use is negligible on the more northerly Forests, such as the Kaibab and Carson. Exclusively summer use is common on the Coconino, Sitgreaves, and Carson, whereas grazing in the winter only is practiced to some extent on the Kaibab and Santa Fe.

Grazing Systems

Continuous grazing, with little or no concern for the needs of the plants, has been the prevailing system on most woodland ranges for centuries. Only in fairly recent times have various rotation or deferred systems of grazing been adopted. Through the efforts of the conservation agencies, increasingly larger acreages of private as well as public land are being brought under more intensive grazing management. Both the Forest Service and Bureau of Land Management have made substantial progress toward institut-

Table 3.--Season of use for the pinyon-juniper allotments on the National Forests of Arizona and New Mexico

National Forests	Percent of total pinyon-juniper acreage				Allotments with 67% or more pinyon-juniper range			
	Yearlong	May 1-Oct. 31	Nov. 1-Apr. 30	Other	Yearlong	May 1-Oct. 31	Nov. 1-Apr. 30	Other
	Percent				*Number*			
Apache	94	5	1	0	88	4	8	0
Carson[1]	0	88	0	12	0	67	0	33
Cibola	68	10	18	4	52	16	27	5
Coconino	19	41	39	1	17	29	50	4
Coronado	65	0	34	1	61	0	37	2
Gila	91	2	6	1	80	3	14	3
Kaibab	6	34	60	0	10	30	60	0
Lincoln	93	3	4	0	84	6	9	1
Prescott	93	0	7	0	81	0	19	0
Sitgreaves	32	53	15	0	15	70	15	0
Tonto	98	0	0	2	95	0	0	5
Santa Fe[1]	4	8	72	16	14	29	43	14

[1] Incomplete data.

ing grazing systems on woodland ranges under their administration.

More than half of the National Forest woodland ranges now are under some form of deferred or deferred-rotation grazing (table 4). Of several grazing systems recognized, the most commonly used on woodland ranges in Arizona and New Mexico is rest-rotation. With this system, grazing is deferred on various parts of a range in successive years, allowing the deferred part complete rest for 1 year. Two or more units are required. Also in fairly common use are deferred grazing and deferred-rotation grazing. Straight rotation grazing, utilizing two or more pastures, is practiced on about 12 percent of the National Forest woodland.

Improving Forage Production

Seeding

For successful seeding in the pinyon-juniper type, control of the tree overstory usually is necessary. The range may be seeded during the actual tree control operations, particularly in conjunction with chaining. Seeds usually are broadcast with a mechanized seeder and covered with a harrow, chain, or similar equipment. On large-scale projects where trees are double chained, seeds commonly are aerially broadcast between the first and second chaining. Another common practice is to distribute seeds in the pits and disturbed soil where trees have been dozed.

Table 4.--Grazing systems used on pinyon-juniper ranges on the National Forests of Arizona and New Mexico (percent of total pinyon-juniper acreage)

National Forests	Percent of total pinyon-juniper acreage used for each grazing system									
	Continuous	Once over	Rotation (No. pastures)			Deferred	Rest-rotation	Deferred-rotation	Rotational deferment	Other
			Two	Three	Four or more					
	Percent									
Apache	30	0	1	0	0	53	14	2	0	0
Cibola	6	0	5	6	0	1	17	8	7	50
Coconino	15	0	5	0	0	20	23	26	0	11
Coronado	21	0	4	4	7	17	2	24	5	16
Gila	23	0	1	1	1	5	39	21	6	3
Kaibab	24	0	0	0	0	17	49	0	10	0
Lincoln	26	0	3	2	0	5	23	40	0	1
Prescott	25	0	2	0	0	55	1	1	0	16
Sitgreaves	8	0	1	23	29	0	39	0	0	0
Tonto	15	0	0	0	0	8	8	66	0	3
Average	19	0	2	4	4	18	22	19	2	10

Seeds can be distributed and planted with a drill only where the land has been cleared of debris left during the control operations. In some areas, undesirable understory vegetation must be eliminated before drilling. Plowing has been the most effective seedbed preparation method. On plowed seedbeds, the best method of seeding is conventional drilling, using double-disk furrow openings with depth bands. On nontilled seedbeds, furrow drilling—with furrows more than 12 inches wide and deeper than 2 inches—can be expected to give better seedling establishment than conventional drilling (Lavin et al. 1973).

Crested wheatgrass can be successfully seeded in northern New Mexico and Arizona, especially where big sagebrush is the principal understory species (fig. 15). Weeping lovegrass appears well adapted in eastern and central Arizona in areas below the Mogollon Rim where summer rainfall is high and winter temperatures mild. Other species that appear widely adapted in the pinyon-juniper include western wheatgrass, Russian wildrye, sideoats and blue gramas, sand dropseed, spike muhly, yellow or Turkestan bluestem, sweetclover, and fourwing saltbush (table 5). Yellow bluestem and Russian wildrye appear to fit situations where winter precipitation is insufficient for crested wheatgrass. Blue grama, especially the Lovington variety, is adapted to most areas in the woodland type.

Figure 15.—Crested wheatgrass is suitable for seeding pinyon-juniper ranges characterized by cold, wet winters.

Soil moisture probably is the main consideration in seeding pinyon-juniper ranges. Cultural practices that concentrate and conserve moisture usually are the most effective. Methods that provide or maintain a

Table 5.--Species adapted for seeding woodland ranges in the Southwest, according to winter climate (adapted from Springfield 1965, USDA-FS 1970, and Lavin's studies as reported by Renney 1972)

Species	Soil	Winter climate and precipitation (inches)				Annual precipitation (inches)		
		Cold		Warm				
		Dry (4-6)	Wet (7-9)	Dry (4-7)	Wet (7-9)	<14	14-16	>16
Wheatgrass, western	Loam, clay	x	x	x	x		x	x
pubescent	Loam, clay		x				x	x
crested	Loam		x			x	x	
intermediate	Loam, clay		x					x
Wildrye, Russian	Loam, clay	x	x	x		x	x	
Grama, blue	Sandy, loam	x	x	x		x	x	x
black	Sandy, loam			x	x	x	x	
sideoats	Sandy, loam	x	x	x	x	x	x	x
Lovegrass, Boer	Sandy, loam			x	x		x	x
Lehmann	Sandy, loam			x	x	x		
weeping	Sandy, loam			x	x		x	x
Dropseed, sand	Sandy, loam	x	x	x	x	x	x	
Muhly, spike	Loam, clay	x	x	x	x		x	x
Bluestem, Turkestan (yellow)	Sandy, loam	x	x	x	x		x	x
Ricegrass, Indian	Sandy, loam	x	x			x	x	x
Sweetclover	Sandy, loam, clay	x	x	x	x	x	x	x
Alfalfa	Loam	x	x				x	x
Burnet	Loam	x	x	x	x		x	x
Saltbush, fourwing	Sandy, loam, clay	x	x	x	x	x	x	x

mulch on the soil surface generally result in better seedling establishment of desirable shrubs as well as grasses. Several mulches have proved effective, including tree branches, dead grasses or forbs, straw, plastic film, petroleum resin, and asphalt. Brush mulch was found beneficial not only in establishment but also in the maintenance of several seeded species on woodland ranges in central Arizona (Judd 1966). A special form of mulching consists of killing the competing vegetation in place with herbicides (Gomm and Lavin 1968). Black plastic mulch improved establishment of cercocarpus at a woodland site near Santa Fe, New Mexico (Springfield 1972).

Tree Control

Although snakeweed, rabbitbrush, pingue, and other noxious plants are common on Southwestern woodland ranges, the main concern is with control of the trees themselves. Most studies have shown that as tree overstory increases, forage decreases. Large-scale efforts have been undertaken to convert woodland to grassland. Control methods may be classified as (1) mechanical, (2) chemical, and (3) burning.

Mechanical.—Control of pinyon-juniper dates back to when the trees were felled with axes to make room for crops. Individual farmers and ranchers also cut trees to open up their pastures for more grazing. Most of these efforts were small scale. Relatively large-scale removal of pinyon-juniper on private land began about 30 years ago. The acreage controlled annually increased to 164,000 acres in 1959 (Cotner 1963), most of it by cabling, the least expensive method. For several reasons the trend reversed in the 1960's; fewer acres were cabled, and more acreage was treated by other methods.

Evidence from the Fort Apache Indian Reservation dramatized the potential advantages from controlling pinyon-juniper. By 1954, 80,000 acres of the Reservation had been cleared. The benefits from clearing were readily apparent. Under dense stands of trees herbage production was less than 100 pounds per acre, whereas after clearing production increased to more than 600 pounds (Arnold and Schroeder 1955). The increase in production was gradual; 350 pounds per acre 3 years after control, 500 pounds in 5 years, and 650 pounds in 10 years.

Not all pinyon-juniper control in Arizona and New Mexico has been that successful, however.

Cabling, the most popular method for several years, fell into disfavor because it proved ineffective on many areas (fig. 16). The method is suitable to even-aged stands of trees 15 to 25 feet tall on shallow, limestone sites. In a mixed stand where half of the trees were less than 6 feet tall and the soil was clay, however, cabling killed only 43 percent of the trees (Cotner 1963). Moreover, the trees that survived cabling often were stimulated to grow two to three times faster due to release from dominance by the taller trees. The tree stands thus ended up more dense than the original.

Chaining generally is more effective and is more frequently used than cabling. Single chaining kills most of the older, larger trees, but leaves the young trees. Double chaining, usually in the opposite direction, increases the percentage of killed trees. For example, Aro (1971) reported the following averages for sites with 180 pinyons and 160 junipers per acre:

	Tree kill
	(*Percent*)
Single chaining	38
Double chaining	60

Single chaining killed 61 percent of the trees where half or more of the trees were taller than 10 feet, but only 30 percent of the trees where more than half were shorter than 10 feet.

Chaining that kills a high percentage of old trees but leaves many young ones can create an ecological situation more difficult and expensive to treat than the original (Aro 1971).

Besides the many small trees not killed, another disadvantage of chaining is the large amount of debris left on the ground. The amount varies with size and density of the trees, and with the method of control. Daniel et al. (1966) related the control method to the tree kill and slash cover as follows:

	Tree kill	**Slash cover**
	(*Percent*)	
Cabled	57	19
Chained one way	70	10
Chained two ways	83	13
Burned	96	6

The tree crown debris interferes with forage utilization and livestock movements. This is not a permanent loss, however. As the dead crowns deteriorate they gradually allow much of the forage to become available in 5 to 10 years.

Burning and other followup treatments have been used to remove excess slash and, at the same time, kill many of the young trees left alive. The burning should be done after the needles dry but before they drop.

The recommendation is to use cabling or chaining on medium-dense, mature stands on fairly smooth terrain. Optimum cost/benefit ratios are achieved where there is 3 to 11 percent tree cover. Neither chaining nor cabling effectively kills trees less than 10 feet tall.

A high proportion of the trees must be large for chaining or cabling to be effective. Small pinyons and junipers less than 3 inches in diameter (1 foot above the ground) rarely are knocked down by chaining. Trees in the 3- to 5-inch diameter class usually are

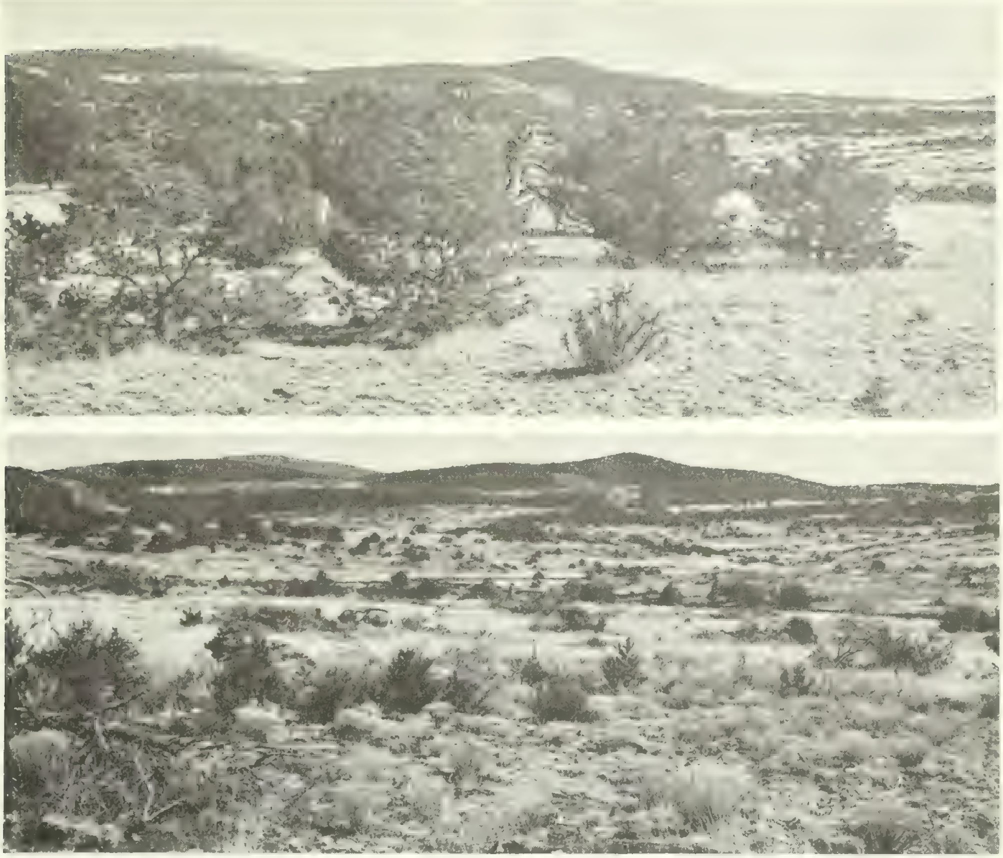

Figure 16.—Cabling proved ineffective on many areas. Prior to cabling, this area supported a mixture of large and small trees **(top)**. Cabling missed many small trees **(bottom)**, which will be stimulated to grow faster and will eventually dominate the area.

knocked down but may not die. Pinyon appears more likely to die after being pushed over than juniper. Junipers, even those 6 to 9 inches in diameter, may survive unless the root system is severely injured. Daniel et al. (1966) determined the percentage of the stand that would have to be greater than 7 inches in diameter to achieve acceptable tree kill at 75 percent and 95 percent as follows:

	Tree kill of —	
	75%	95%
Cabling	85	100
Chained one way	60	85
Chained two ways	45	78

A combination method involves chaining followed by windrowing. The windrowing consists of scraping the downed trees, together with some soil, into long ridges. This operation not only removes most of the young trees missed by the chain, but it also eliminates many undesirable plants such as snakeweed. After indrowing, some form of revegetation ordinarily is quired. Drilling is preferable to broadcast seeding. rding to Aro (1971), the chaining-windrowing technique is the most effective mechanical method of replacing trees with grass. Daniel et al. (1966) indicate that criteria include slopes not exceeding 15 percent, and soils at least 2 feet deep with a sandy or silt loam surface. They also state that site characteristics that indicate high productivity from seeded grasses in the 15- to 16-inch precipitation zone are (1) the tree canopy prior to treatment is 36 percent; (2) pinyons are 30 feet tall, or junipers are 22 feet tall; and (3) total soil depth is 30 inches, with a 6-inch A-horizon of sandy loam texture and 5-percent stoniness.

As Aro (1971) points out, ecological criteria restrict the chaining-windrowing method to certain sites that will usually produce greater benefits when converted to grassland than if left untreated. Stony, wooded ridges and canyon slopes, which are better suited to trees and browse, will be left intact as wildlife habitat.

Pushing and uprooting individual trees with a bulldozer is a good method in light or medium-dense stands of pinyon-juniper. A variety of equipment is available, including the conventional straight blade, or modifications such as the Huladozer, stinger, or pusher bar. An advantage of this method is that certain trees can be left for shade or esthetics. The method works best when there is adequate soil moisture, but not when the ground is frozen or too wet. Because of the large amount of forage covered by downed trees, followup stacking or windrowing—and possibly burning—is desirable. Broadcasting seed in pits left by the trees and on other disturbed areas also is desirable. Bulldozing is recommended in mixed-age stands up to 100 trees per acre, or when the tree cover is 3 to 11 percent.

Hand chopping, sawing, or grubbing is practical for scattered trees on small areas, or as a cleanup method. This is the most thorough of all mechanical methods, but the labor costs are high. Removal of wood products such as posts, firewood, and Christmas trees may help offset the costs.

Tree crushing is one of the most effective methods for controlling dense stands of pinyon-juniper. The tree crusher moves through the trees like a giant brush cutter (fig. 17A), pushing them out of the ground, cutting them up into fireplace-sized pieces (fig. 17B), and creating openings for livestock and wildlife (Lamb 1970). The method is especially well suited for sizable areas with a remnant stand of grasses and forbs that will respond to removal of tree competition, and to areas where esthetics are important (Williamson and Currier 1971). It is limited to relatively nonstony soils and to slopes of less than 15 percent.

Chemical.—Tree-killing chemicals have not been widely used for controlling pinyon-juniper because the trees are somewhat resistant to most herbicide treatments. According to Johnsen (1967), more is known about control of juniper than of pinyon. Effective herbicides applied to the foliage and stems of juniper include: arsenite, AMS (ammonium sulfamate), esters of 2,4-D and 2,4,5-T, and PBA (polychlorobenzoic acid). To control individual junipers by foliage treatment requires thorough coverage. Rates of 8 to 16 pounds of acid equivalent per hundred gallons of spray are needed with these chemicals.

Herbicides that are effective when applied to the soil surface around the base of the juniper tree include pelleted fenuron and granular TBA (tri-

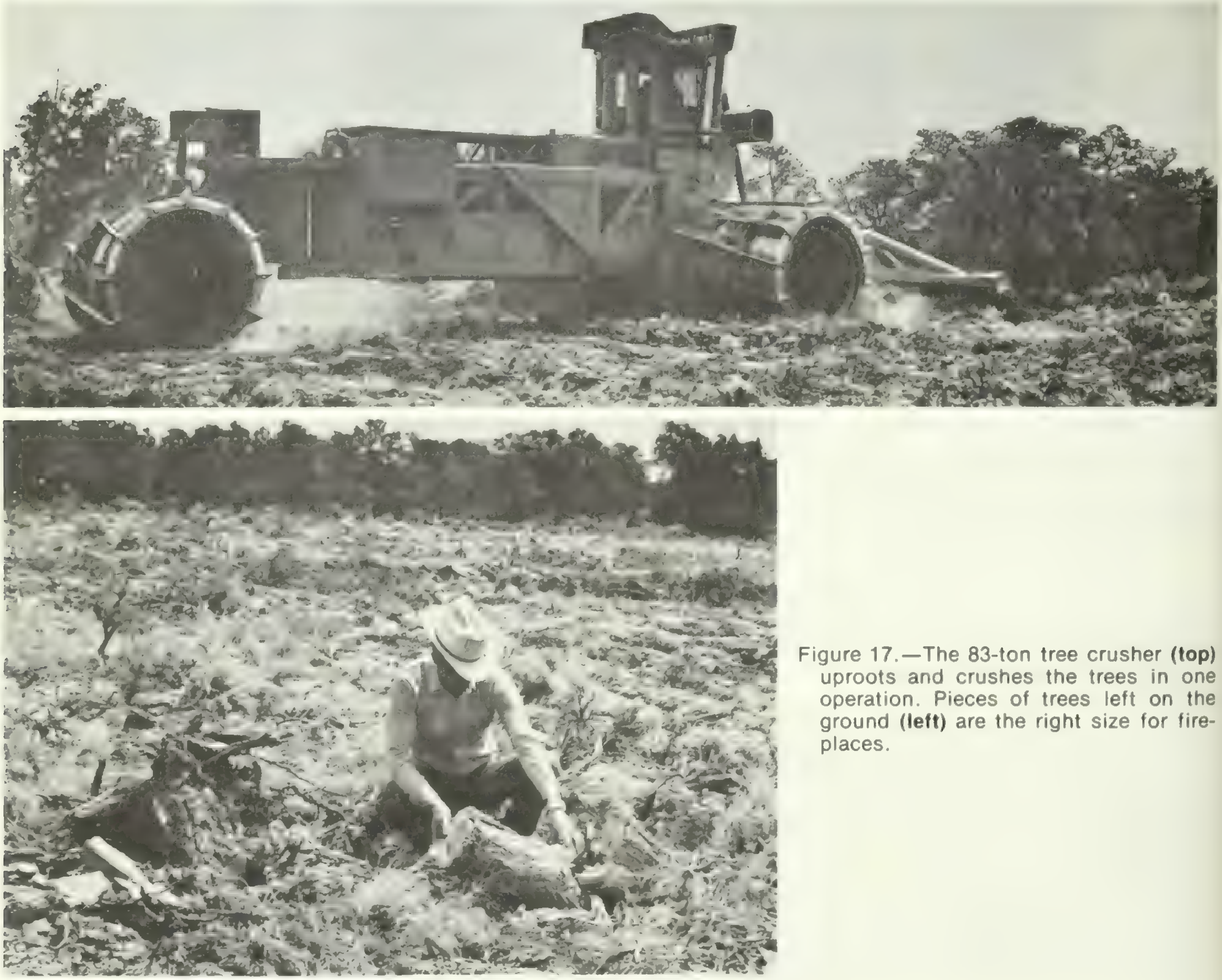

Figure 17.—The 83-ton tree crusher **(top)** uproots and crushes the trees in one operation. Pieces of trees left on the ground **(left)** are the right size for fireplaces.

chlorobenzoic acid). These two chemicals have been effective when applied to the tree base at about 1 tablespoon of material per 3 feet of tree height, for trees up to 12 feet tall. Higher rates are needed on fine-textured soils. Picloram is effective when applied to the foliage at 1 pound acid equivalent per hundred gallons as a wetting spray, or at 7.5 pounds active ingredient per acre as pellets.

Information concerning the effects of herbicides on pinyons is scarce (Johnsen 1967). Pines generally are resistant to foliage sprays of 2,4-D, 2,4,5-T, and PBA. AMS, however, has been effective as a foliage spray or as a frill treatment (Herman 1954). Pelleted fenuron applied to the tree base at the rate of 1 tablespoon per 3 feet of height has killed pinyon on loam soils, and picloram seems effective as either a foliage or soil treatment (Johnsen 1967).

Burning.—Burning ordinarily does not afford a high degree of site selection but it can be effective. Arnold et al. (1964) consider four situations where burning is useful in the pinyon-juniper: (1) broadcast burning, (2) burning individual trees, (3) burning grassland areas, and (4) burning slash.

Broadcast burning of mature stands of pinyon-juniper requires special conditions. The stands must be dense and the burning must be done during hot, dry, windy weather. It is a hazardous operation; the risk of escape is high. But there are a number of examples of the effectiveness of prescribed burning, especially on the Hualapai Indian Reservation. From 1955 through 1963, the Hualapai Indians burned and seeded 17,000 acres of pinyon-juniper at a cost of $4.50 per acre. Forage production was increased about 500 pounds per acre.

Burning individual trees is best suited to open stands, especially small trees of one-seed or Utah unipers (Jameson 1966b). The method is not appropriate for trees more than 10 feet tall, nor for sprout-ng species. Large trees require too much time, naking the cost prohibitive. Small trees, however, are quickly burned. Jameson (1966b) reports a stand of 00 trees 10 feet tall would take two men a total of about 35 minutes. Either propane or oil-burning torches are suitable (fig. 18). Leaf scorch is the most useful indicator of mortality. For 100 percent kill of juniper, 60 percent of the crown should be corched. An advantage of the method is that indi-idual trees can be burned at any season.

Burning of grassland communities to control nvading junipers and pinyons has been tried on a mited scale. Grazing must be deferred for a growing season so that enough fuel accumulates to carry the re. Protection from grazing also is desirable for a rowing season following the burn. Based on studies f lethal temperatures, Jameson (1961) concluded rasses such as the gramas and galleta were likely to e damaged by fires during the summer months; herefore he suggested prescribed burning when the air is cooler and more humid. In later studies on galleta-black grama range, however, he found that, 2 years after fires in January, March, and June, grass production and cover were essentially the same as prior to burning (Jameson 1962). He reported 70 to 100 percent of the one-seed junipers less than 4 feet tall were killed by fire, compared with only 30 to 100 percent of the trees 5 to 6 feet tall.

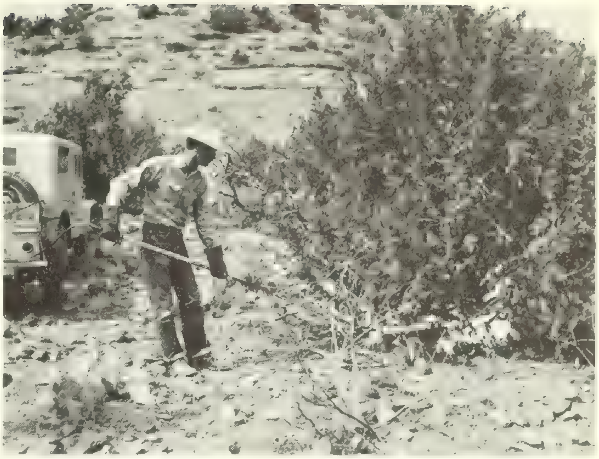

Figure 18.—Gas burner being used to kill a juniper (from Arnold et al. 1964).

Guidelines.—Guidelines for pinyon-juniper control are available. The New Mexico Inter-Agency Range Committee (1968) recommends limiting treatment to stands on soils 18 inches or more deep when the objective is to increase grass production.

The Arizona Interagency Range Technical Sub-Committee (1969) recommends chaining or cabling for stands of mature trees in excess of 100 trees per acre. They suggest broadcast burning of dense stands where pinyon is a component. Individual tree burning is recommended on stands of young trees up to 100 trees per acre. Bulldozing is recommended in mixed-age stands up to 100 trees per acre.

The USDA Forest Service Region Three Nonstructural Range Improvements Handbook (1970) briefly describes and points out the limitations of several control methods (table 6). Recommendations call for treating slopes of 20 percent or less, leaving some northeast exposures untreated for wildlife, and designing treatment boundaries to blend into the landscape. Treatment areas should be of a size and shape beneficial to wildlife. If islands of trees are left, they should be long and slender, and at least 10 acres in size. Width of openings should not exceed ¼ to ½ mile.

Plant response to tree control.—Response of the understory vegetation to removal of tree competition varies according to soil and climatic characteristics, species composition, and density of the understory and other factors. In northern Arizona, removal of

Table 6.--Methods of pinyon-juniper control (extracted from Nonstructural Range Improvements Handbook prepared by Southwestern Region, R-3, USDA-FS 1970)

Method and type of equipment	Time	Limited to	Remarks
TREE CRUSHING Modified tree crusher.	Use when ground is not frozen or when excessive moisture is not present.	Large acreages of non-stony soils on slopes of less than 15 percent. Optimum benefit-cost ratio in very dense stands.	Gives good results with high esthetic values.
BURNING Propane torches; fire control equipment.	Spring or summer.	Light infestations of small trees for individual tree burning. Optimum benefit-cost ratio with light stands.	Gives good results, and warrants wider use. May be used following chaining.
CHAINING (CABLING) Chain weighing 70 pounds or more per link.	Any time except when ground is frozen.	Large acreages of mature, even-aged trees. Optimum benefit-cost ratio with light and medium stands.	Fire for debris cleanup must be part of the treatment.
CHOPPING Brush chopper.	When seeding is needed, coincide with seeding time.	Little trees in small, odd-shaped areas.	Limited application; gives fair results. Poor results on alligator juniper.
ROTOCUTTER Highway-type mower. Heavy duty rotary mower.	Treat when least damaging to associated species.	Areas with small trees and no stones.	Gives good results. Will not kill alligator juniper. Desirable treatment for new invasion.
PUSHING (DOZING) Wheel or track-type tractor with blade or "stinger."	All year. Do not push alligator juniper when ground is frozen.	Light and medium stands.	Burning, windrowing, or stacking debris where necessary should be a planned part of the treatment.
HAND GRUBBING Grubbing hoe.	All year except when frozen.	Light and medium infestations of small trees.	Gives good results. Use as followup treatment or on new invasion.
HAND CUTTING Ax or saw.	All year.	Light infestations.	Gives good results except on alligator juniper, where it is ineffective. Wood products may return part of cost.
CHEMICAL SOIL STERILANT Fenuron-- Rate: Trees less than 6 ft high, 1 T. on light and medium soils; 2 T. on heavy soils. Double amounts for trees 6-12 ft high.	July to September.	Light stands only.	For other chemical treatment, see Section in Handbook on Chemical Control of Range Weeds.
CHEMICAL STUMP TREATMENT Ammate crystals; or 2,4-D and 2,4,5-T with diesel; or Benzae 94.	At time of cutting.	Light stands only.	Alligator juniper only.

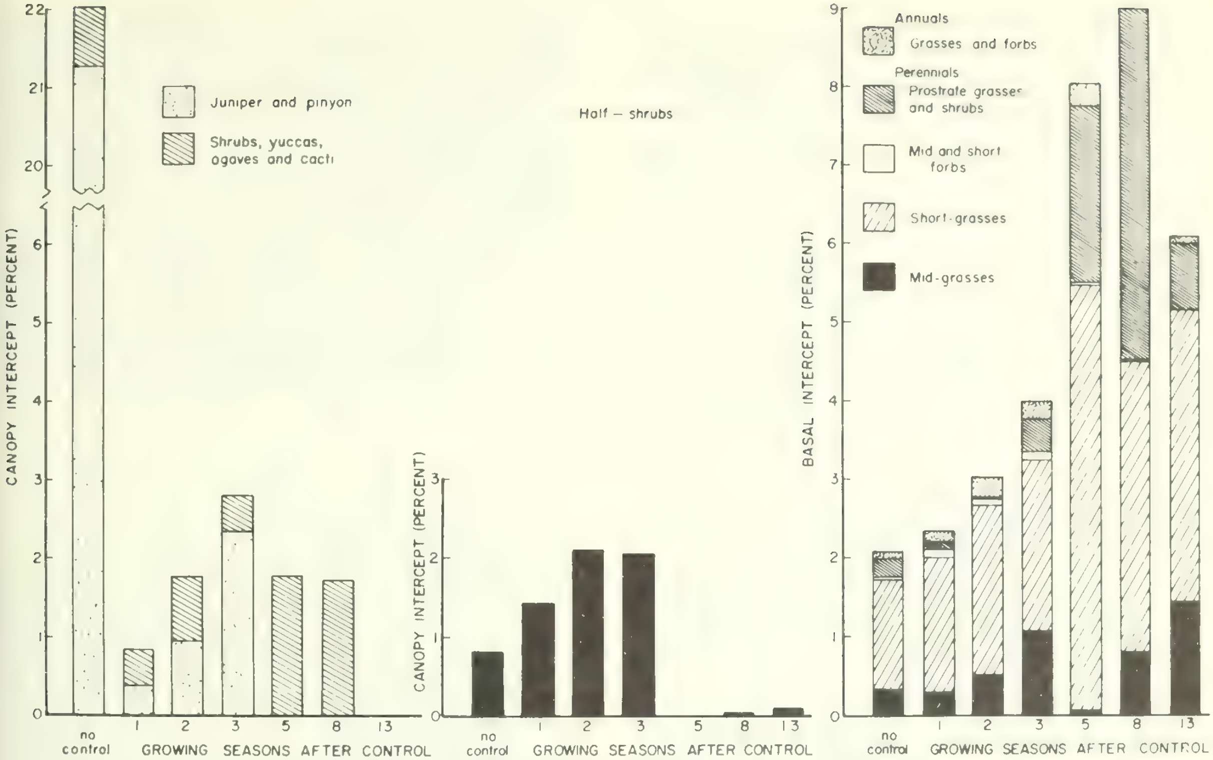

Figure 19.—Changes in plant cover of (left) woody species, (center) half-shrubs, and (right) herbaceous species following pinyon-juniper control (from Arnold et al. 1964).

the trees resulted in a marked increase in half-shrubs, primarily snakeweed (Arnold et al. 1964). Snakeweed increased steadily for two or three growing seasons, then abruptly declined (fig. 19). Mid-grasses, particularly threeawns and sideoats grama, increased with seasons after control. Western wheatgrass responded rapidly to tree removal, especially on heavy soils. Of the short-grasses, blue grama was by far the most mportant; it continued to increase through the fifth year after control. Annuals increased the first two growing seasons, but by the fifth season they had been largely displaced by perennials. Herbage production increased each year, reaching a maximum about the tenth year after control (fig. 20).

Understory vegetation does not always improve greatly with removal of the overstory. For example, on the Heber Ranger District of the Apache-Sitgreaves National Forest, no improvement in the understory resulted where calcium carbonate in the urface soil was about 13 percent and the tree overstory 13 to 26 percent. Perennial grass yields inreased severalfold, however, where the carbonate was only 5 percent and the tree overstory 36 to 44 percent (O'Rourke and Ogden 1969). Crown cover of trees, together with calcium carbonate in the surface oil, may be useful for predicting understory reponse.

The advisability of controlling Utah juniper on ery stony, clay Springerville soils has been quesoned due to the difficulty in revegetating these soils.

Ten years after tree control, some areas on Beaver Creek still grew mainly snakeweed and goldeneye; those areas that initially had little native perennial grass still were producing no more forage than

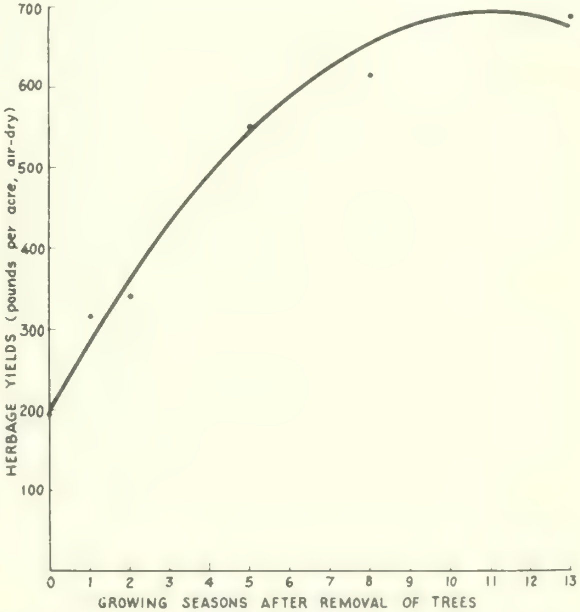

Figure 20.—Herbage yields by number of seasons after tree control (from Arnold et al. 1964).

untreated areas (Clary 1971). Where seeded grasses were successfully established, however, perennial grass yields increased rapidly, peaked in 4 to 6 years, then declined. Areas with Springerville soils can be expected to support mainly forbs and half-shrubs for years after tree removal unless considerable perennial grass is present before treatment or revegetation attempts are successful.

Costs.—Costs of pinyon-juniper control vary with density and size of the trees, topography, methods used, and acreage to be treated. Some of the early cost figures, particularly costs for hand chopping on Indian lands, no longer appear valid. Likewise, costs for tree crushing appear somewhat conservative. Nevertheless, sufficient cost information is available for comparisons.

Cabling and chaining generally are the least expensive methods. One of the most expensive, based on published data, is clearing alligator juniper with chain saws (Miller 1971); costs for felling the trees, piling the slash, and spraying the stumps totaled $45 per acre. Barger and Ffolliott (1972) show cabling or chaining a heavy stand of mature trees costs $5 to $6 per acre (table 7).

According to the New Mexico Inter-Agency Range Committee (1968) costs per acre were as follows:

	Cost/acre
Tree crusher	$7.50 to 10.00
Pushing or dozing	5.00 to 7.00
Chemical	4.50
Hand cutting	Up to 6.00
Chaining (one-way)	3.50
Individual tree burning	1.75 to 1.90

Costs for tree crushing in 1975 ranged from $15 to $25 per acre. Likewise, costs of the other practices have increased substantially. As examples, Clary et al. (1974), using 1972 conditions, estimate $9 and $13 per acre as the cost for pushing and piling a stand of 125 trees per acre. Followup cleaning and slash burning costs vary from $2 to $4 per acre, and seeding costs are estimated at $4.20 per acre. Total cost for juniper conversion in an operational-sized project would then be about $19.69 per acre in 1972 (Clary et al. 1974).

An analysis of the economic aspects of pinyon-juniper control on medium-sized ranches in New Mexico (Gray et al. 1965) shows the following per-acre job costs in 1961:

Practice 1	
Pushing trees	$14.00
Seedbed preparation	.98
Drilling seed	2.66
Deferred grazing	.50
Fencing	5.48
	$23.52

Practice 2	
Chaining (one way)	$4.00
Aerial seeding	2.63
Deferred grazing	.50
Fencing	5.48
	$12.61

Over a 10-year period, only 3 percent of net income of the ranch would be required to meet the annual payment for chaining 267 acres of pinyon-juniper (table 8). If the tree stands are not too heavy, the costs per acre for controlling them are relatively modest.

Table 7.--Costs per acre of control treatments in southwestern pinyon-juniper stands by stand size and density (adapted from Barger and Ffolliott 1972)

Operation and method	Stand	Density	Cost per acre	Source
			Dollars	
Tree clearing:				
Cabling or chaining	Mature	Heavy	5.00- 6.00	Worley and Miller (1964)
	Mature	Medium	Average 3.50	N.M. Inter-Agency Range Comm. (1968)
	Mature	Light-medium	1.22- 2.33	Cotner (1963)[1]
	Small	Light-medium	.95- 1.46	Cotner (1963)[1]
Pushing	Mature	Heavy	8.00-14.00	Worley and Miller (1964)
	Mature	Light-medium	5.00- 7.00	N.M. Inter-Agency Range Comm. (1968)
	Mature	Light-medium	3.72-10.90	Cotner (1963)[1]
	Small	Light-medium	3.13- 7.66	Cotner (1963)[1]
Hand cutting, piling	Mature	Heavy	45.00-55.00	Worley and Miller (1964)
	Mature	Heavy	Average 45.02	Miller (1971)
	Small	Light	Average 6.00	N.M. Inter-Agency Range Comm. (1968)
Cleanup following pushing and cabling			2.00- 6.00	Worley and Miller (1964)
			Average 6.00	N.M. Inter-Agency Range Comm. (1968)
Slash burning			.50- 1.00	Worley and Miller (1964)

[1] Predicted costs, based on analysis of experienced costs.

Table 8.--Proportion of net income of a medium-sized ranch (245 animal units) required to pay for controlling trees (Gray et al. 1965)

Control method	Size	Total cost	Percent of net income required to meet annual payments		
			5 yr	10 yr	15 yr
	Acres	*Dollars*	- - *Percent* - -		
Handcutting	1,144	2,357	8	5	4
Dozing	267	3,738	20	11	8
Chaining	267	1,068	6	3	3

but when the stands are dense, the costs per acre may be excessive. Few ranchers can afford to control heavy stands on large portions of their ranches without financial help. According to Gray et al. (1965), ranchers could receive the following payments under the Agricultural Conservation Program: pinyon-juniper control, 66 percent of total cost; reseeding, 50 percent of cost; and fencing, 44 percent of cost.

The benefits are rather difficult to assess, but Cotner and Kelso (1963) calculated that reduced labor and increased beef sales resulting from juniper control were worth $1.19 to $3.89 per acre to ranchers in 1963. On one allotment on the Prescott National Forest, bulldozing 7,100 acres of juniper at a cost of $8,412 allowed an increase in cattle from 4,480 animal units before treatment to 7,500 animal units after treatment (Beveridge and Ames 1956).

Several benefit-cost analyses have been made recently of juniper control projects in Arizona (Clary et al. 1974). Juniper control was shown to be not economically feasible where gains in potential grazing capacity were less than 0.12 AUM per acre. Where the gain in potential grazing capacity is 0.27 AUM per acre, however, the total benefit to ranching amounts to as much as $23 per acre (7.0 percent interest), which gives a net positive difference of more than $3 per acre. Clary et al. (1974) conclude that, based on 1972 technology, costs, and values, identifiable economic benefits and costs come out about even for the more successful juniper control projects.

Fertilizer Applications

Fertilization of pinyon-juniper ranges in the Southwest has been limited to small-scale tests, mainly in south-central New Mexico. Blue grama range at Fort Stanton was fertilized with 40 or 60 pounds of nitrogen per acre each year from 1965 to 1971 (Dwyer 1971). Grass production more than doubled where 60 pounds of nitrogen was applied. Six-year average yields were:

	Grass production *(Lb/acre)*
No fertilizer	493
Fertilized with nitrogen:	
40 lb/acre	949
60 lb/acre	1,223

A 138-acre pasture at Fort Stanton was also fertilized with 40 pounds of nitrogen per acre for 3 years (Dwyer and Schickendanz 1971). Herbage production increased sufficiently to warrant doubling the stocking rate—from 12.5 acres per head for unfertilized range to 5.0 acres per head for fertilized. Gains of heifers over the 3 years averaged 23 pounds per acre on unfertilized range compared to 48 pounds on fertilized range.

Management Considerations

All factors considered, the best use of pinyon-juniper lands in the Southwest is to provide forage for grazing animals. Situated as they are between the desert and the pine forests, woodland ranges may hold the key to balancing livestock numbers with forage supplies in the Southwest. Although the possibilities for improving woodland ranges have not been fully explored, these ranges could conceivably support more livestock if they were improved to their maximum capability by plant control, seeding, fertilizing, proper stocking, and management. Some woodland ranges can definitely be improved through deferred, rotation, or other systems of grazing. Any rehabilitation program should be geared to the potential of the specific area to respond to either (1) grazing management to improve range condition, or (2) manipulation of the plant cover to increase forage production.

Manipulation of Tree Cover

A decision to manipulate the plant cover should be based on sound ecological principles. Areas with at least 15 inches of annual precipitation, moderately deep soils, slopes less than 15 percent, and fairly dense tree cover offer the best possibilities for manipulation.

Daniel et al. (1966) suggested using aerial photos to evaluate the potentials of pinyon-juniper areas for forage production. Percent crown canopy estimated from aerial photos can be in tree canopy-herbage production relationships to estimate potential forage production.

Besides considering potential productivity, the land manager must decide which tree stands can be optimally controlled by one of the several methods available. Factors that influence this decision are (1) rate of forage decline due to increases in tree growth, (2) rate of forage increase after control, and (3) rate of change of treatment costs. Decline of forage production due to increase in tree cover with time has been estimated from equations, as has the recovery of forage following tree control (Jameson 1971). The average recovery rate was found to be 92 pounds per acre per year from the time of tree control until the level of forage production without trees is reached (400 lb/acre for blue grama; 600 lb/acre for midgrasses).

Rate of change of the costs of various control methods, including cabling and burning, also were calculated. According to Jameson (1971), the optimum time for a given control operation is when rate of change in benefits equals the rate of change in costs. The optimum cover for individual tree burning is 1 to 3 percent for all tree stands of 20 to 180 trees per acre. For cabling, the optimum is 4 to 6 percent tree cover; many stands suitable for cabling have already been treated.

The optimum cover for bulldozing increases with number of trees. On a short-grass site, for example, optimum cover for bulldozing ranged from 2 percent with 20 trees per acre to 12 percent with 200 trees per acre. The results of Jameson's study apply to variable-cost treatments. For a fixed-cost method, such as tree crushing, the timing is optimum when the rate of change in benefits is zero; that is, when the tree cover reaches a maximum and forage production is minimum—usually when the tree cover is 25 percent or more.

Control of sparse stands of pinyon-juniper for the primary purpose of improving browse production may not be warranted. Thus, on the North Kaibab Ranger District, production of cliffrose was 2.7 times greater where a thin pinyon-juniper stand (15 trees per acre) had been bulldozed 4 to 6 years earlier, but the total yield of cliffrose was only 3.5 pounds per acre more on the treated than on the untreated areas. This increase could hardly be very significant in terms of total needs of the deer (McCulloch 1966). Later studies in the same area revealed no increase in cliffrose density 11 years after tree control (McCulloch 1971).

Pinyon-juniper control areas should be kept relatively narrow so that deer using the created openings are never far from cover (New Mexico Inter-Agency Range Committee 1971). Ideally, the openings should not be more than ¼ mile wide. Abundance and condition of native shrubs in the understory influence the choice of control method. Chaining ordinarily does the least harm to useful shrubs such as cliffrose, mountainmahogany, and serviceberry, whereas other methods may practically destroy valuable understory plants unless the equipment operator has been trained.

Burning dense woodland on fairly rough terrain to improve range conditions for both cattle and deer may be an acceptable practice, according to McCulloch (1969). His studies of wildfires and prescribed burns over a 20-square-mile area on the Hualapai Indian Reservation showed live tree cover was completely destroyed by the fires. Despite the large acreage burned, only 5 percent of the burned areas were more than ½ mile from unburned woodland. Consequently, deer using the burned areas were never far from cover. Cliffrose, a major component of the understory on unburned areas, was virtually absent from the burned areas. Nevertheless, deer were more abundant on burned than unburned areas. Nonbrowse items made up 85 percent of the contents of deer rumens collected from burned areas in autumn. The large-scale burns may not have been optimum for deer, but they served the dual purpose of increasing food for deer and cattle.

Guidelines for Grazing Management

Management guidelines given by Humphrey (1955) for woodland ranges in Arizona include (1) leaving a third of the grass culms ungrazed at the end of the season, and (2) resting areas so that grasses can set seed and new seedlings can be established. He recommended resting woodland ranges in poor condition every summer, those in fair condition every other summer, and those in good condition once in 3 years. Pinyon-juniper ranges in good condition generally support a fairly dense understory of desirable grasses such as black, blue, and sideoats gramas, Indian ricegrass, Junegrass, western wheatgrass, galleta, and palatable shrubs, whereas those in poor condition support mainly thin stands of ring muhly, blue grama, and sand dropseed, together with many weeds and half-shrubs, including snakeweed, pingue, and rabbitbrush. Contrary to Humphrey (1955), Jameson (1970) claims snakeweed is unreliable as an indicator of range condition in the pinyon-juniper type.

Dual grazing by cattle and sheep offers possibilities for increasing livestock production. Studies on the Fort Stanton range, where blue grama comprised 66 percent of the forage available, wolftail 17 percent, and sideoats grama 5 percent, showed cattle consistently consumed more grass and sheep more of the forbs (Thelford et al. 1971). For both cattle and sheep, forbs were more important in the fall-spring, and grasses in the summer. The animals preferred sideoats grama over blue grama and wolftail.

Prairie Junegrass and bottlebrush squirreltail are preferred by yearling cattle during spring-fall grazing in the woodland type of northern Arizona (Clary and Pearson 1969). Junegrass was utilized 43 percent and squirreltail 40 percent compared with 33 percent for muttongrass, 30 percent for sideoats grama, and 5 percent for blue grama.

Range readiness in the pinyon-juniper type was investigated near Flagstaff (Jameson 1965b). Cool-season grasses such as muttongrass, Junegrass, squirreltail, and western wheatgrass begin active growth between March 10 and April 10 each year. Height growth of the cool-season grasses between April 10 and May 10 is reasonably predictable; squirreltail, western wheatgrass, and Junegrass grow about ½ inch and muttongrass about 1¾ inches a week. By adding expected growth to existing growth, the time at which these species will reach a given height can be predicted. For example, if grazing is to begin when western wheatgrass is 4 inches tall, and the height on April 10 is 2 inches the predicted date of range readiness would be 4 weeks later, or May 8. Warm-season grasses such as blue, sideoats, and black gramas, galleta, black dropseed, and spike muhly grow slowly from spring to mid-July. They grow rapidly in late July and August, depending largely on summer rains. Because they usually are grazed during the time of effective precipitation, forage production is difficult to predict.

Grazing systems should be designed to allow occasional rest for both the cool- and warm-season grasses. According to Jameson (1965b), three periods should be recognized: summer (July 10-October 15), winter (October 15-April 10), and spring (April 10-July 10). For most of the pinyon-juniper type, cool-season grasses need more protection than warm-season grasses. The period from April 10 to July 1 probably is the most critical for the cool-season species. If warm-season grasses are to be favored, they should be protected from grazing from about July 15 to October 15.

Blue grama growth in northern Arizona can be predicted at the earliest on August 15, according to Jameson (1965b). Maximum height usually is reached by September 12, so the range manager has a 4-week lead to estimate total growth. Maximum height will be about 1 inch plus 1½ times the height on August 15. If, for example, plants are less than 4 inches tall on August 15, they will be less than 7 inches tall by the end of the season; if there is 10 inches of growth on August 15, total height will be about 16 inches.

Blue grama yields are highly correlated with growing season and total annual precipitation in the pinyon-juniper type on Fort Stanton (Pieper et al. 1971). Correlation coefficients for alluvial loamy sites were as follows:

	Herbage production	
Precipitation	**All species**	**Blue grama**
Annual (Oct.-Sept.)	0.81	0.65
Growing season (June-Sept.)	.84	.71

Because production varies directly with precipitation, stocking rates can be adjusted on these alluvial loamy sites to avoid heavy grazing in years of below-average precipitation.

Correlating Grazing with Other Uses

Wildlife.—Pinyon-juniper woodlands are valuable to wildlife. The type provides protective cover and food, including juniper foliage and berries, pinyon nuts, and forage from understory shrubs, forbs, and grasses. Pinyon-juniper is especially important to deer. About one-fourth of the annual deer harvest in Arizona comes from the pinyon-juniper (McCulloch 1969). The type also is valuable to turkeys, elk, antelope, rabbits, squirrels, quail, and many non-game species of birds and mammals.

In the woodland type of southwestern New Mexico, Reynolds (1964) found shrub abundance was the most important factor influencing deer and elk use. Shrubs increased with number of trees to a density of about 150 trees per acre; in denser tree stands, number of shrubs decreased. Elk and deer preferred northeastern exposures. They used slopes up to 40 percent as much as level areas. Based on these results from Fort Bayard, Reynolds recommended coordinating livestock range-improvement practices with game habitat preservation by (a) clearing only slopes less than 15 percent, (b) leaving existing cover on north-east exposures, and (c) on areas reserved for game, removing or thinning trees where the stand exceeds 150 trees per acre.

Browse comprised 86 to 96 percent of mule deer diet during the fall-winter period in the pinyon-juniper type at Fort Bayard (Boeker et al. 1972). During spring and summer, deer used forbs to the extent that browse made up only 58 percent of the diet. The five leading browse species and their percentage contributions to mule deer diets were: mountainmahogany 33, oak 24, juniper 5, Wright silktassel 4, and skunkbush sumac 3. Mountain-mahogany and oak were most important mainly because of their availability. Results of these studies on Fort Bayard indicate habitat management should strive to maintain the mountainmahogany and oaks since they contribute most to deer nutrition (fig. 21). The junipers and pinyons, on the other hand, can be sacrificed from the standpoint of food contribution. The trees also appear unnecessary for cover where there is an adequate stand of shrubs (25 to 50 shrubs per acre).

Other studies on Fort Bayard show habitat for desert cottontails can be maintained during pinyon-juniper control by keeping 70 to 90 living shrubs and/or down, dead trees per acre (Kundaeli and Reynolds 1972). Under natural conditions, cottontails thrived where vegetation per acre averaged 85 trees, 85 shrubs, and 270 pounds of perennial grass. Overstory trees affect cottontails largely by suppressing the shrubs. Cottontails were fewer where shrubs had been suppressed to less than 85 plants per acre. Uprooting, piling, and burning all trees depressed cottontails. Leaving down, dead trees scattered through the control areas proved beneficial except where the density of living shrubs exceeded 70 to 90 per acre.

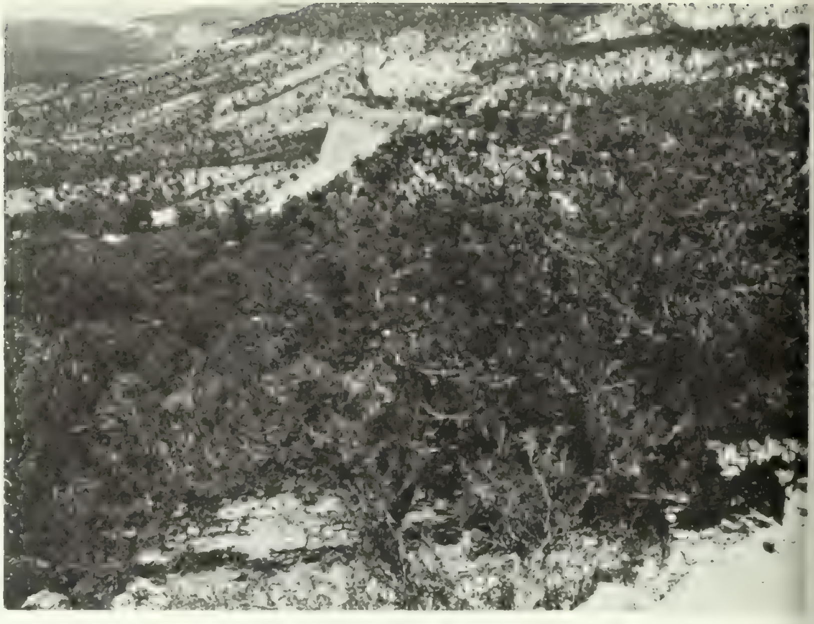

Figure 21.—Where mountainmahogany is abundant and the slopes are steep, the area should be managed primarily as wildlife habitat.

Water.—Opportunities for increasing usable water yield from the pinyon-juniper type are not promising (Dortignac 1960). Studies on pinyon-juniper watersheds showed that runoff constitutes only 2.2 percent of the annual precipitation near Santa Fe and only 4.5 percent near Gallup (Mexican Springs). Runoff in the New Mexico studies came mostly from intense convectional thunderstorms, as these average runoff figures indicate:

Annual rainfall	Runoff Santa Fe	 Mexican Springs
(*Inches*)	(*Inches*)	
<1.01	0.046	0.043
1.01-2.50	.131	.137
>2.50	.193	.335

Results from Arizona studies are similar. Streamflow averages only about 2 percent in the lower pinyon-juniper type, based on these data from Beaver Creek (Brown 1965):

	Annual precipitation class Low	 High
	(*Inches*)	
Lower pinyon-juniper type (Utah juniper)		
Precipitation	13.0	24.0
Runoff	0	.8
Upper pinyon-juniper type (Alligator juniper)		
Precipitation	14.0	30.0
Runoff	.3	5.4

Utah juniper areas contribute much more suspended sediment during periods of streamflow than do alligator juniper areas.

The amounts of rain and snow intercepted by Utah and alligator juniper crowns, and the amounts that reach the ground by throughfall and stemflow, vary with duration and intensity of storms and are predictable (Skau 1964a). Clearing juniper increases water available for producing forage, but has little effect on water yield, according to Skau (1964b). No change in water yield was detected after pinyon-juniper was removed by chaining from one-fourth of an area on sedimentary soils in eastern Arizona (Collings and Myrick 1966).

After several years of careful study of six treated and control Beaver Creek watersheds in central Arizona, Clary et al. (1974) concluded that: (1) mechanical methods of pinyon-juniper removal are not likely to increase water yield; (2) removal of pinyon-juniper overstory by herbicides can increase water yield; and (3) there has been no statistical verification of changes in flood peaks or water quality due to treatment.

Timber products.—The pinyon-juniper type in Arizona and New Mexico contains much wood. For New Mexico alone the estimate is 1.7 billion cubic feet (Choate 1966). Only a small percentage of this wood is utilized. Principal wood products are firewood, fenceposts, and charcoal; other products include pinyon nuts and Christmas trees.

Firewood yields vary with density, age, and composition of the stand. Howell (1940) reported yields averaged 11.4 cords per acre. A study in New Mexico revealed wholesale buyers paid $14 to $18 per cord;

retail prices ranged from $25 to $36 per cord (Sowles 1966). The market for pinyon fireplace wood seems to be growing, whereas that for juniper is diminishing. Profits depend on type of operation and market area; Albuquerque is generally less profitable than Phoenix (LeBaron 1968).

Juniper fenceposts have been an important product of the pinyon-juniper type for many years, because of their outstanding natural durability. In recent years the market for juniper posts has declined; however, Howell (1941) estimated about 46 posts per acre in uncut stands in Arizona and New Mexico.

Charcoal consumption is on the increase, but making charcoal from pinyon and juniper is a speculative venture. Yields of 30 to 35 percent have been obtained (Barger and Ffolliott 1972). Costs of production vary with type of equipment used, capacity, species of wood, proximity to wood source, and labor.

The pinyon nut crop averages 1 to 2 million pounds annually (Little 1941). Pinyon trees produce nuts only at intervals of 4 to 7 years. Crop years differ from area to area, however, so that good crops occur somewhere every year. The better natural stands may yield 300 pounds of nuts per acre during a good year. Pickers usually receive 50 cents to a dollar per pound (1975 rate).

Pinyons are a popular Christmas tree (fig. 22). For example, in 1964, pinyons comprised about 25 percent of all Christmas trees in the six-State area of New Mexico, Arizona, Colorado, Wyoming, Utah, and Nevada, although the demand for pinyons has declined since then (Barger and Ffolliott 1972). More than 6,000 salable Christmas trees were found on a 640-acre area in northern Arizona, and an additional 3,000 small trees (up to 3 feet) were judged to be salable in the future.

A system of grading has been developed specifically for pinyons based on form class, symmetry, foliage density, and color. Quality of the trees can be improved by cultural treatments such as thinning and shearing. Management primarily for Christmas trees, including silvicultural practices such as stump culture, pruning, and weed control, has been advocated for areas with deep soils where growth form of pinyons is suitable (Jensen 1972).

According to Barger and Ffolliott (1972), utilization of wood products should be coordinated with management of the other resources, particularly with programs for controlling the trees. Live, standing pinyons, for example, should be harvested before the control operations because pinyon is nondurable and deteriorates quickly. Junipers, on the other hand, remain durable for many years and can be harvested on the ground after chaining, pushing, or other treatment. Besides its common use for fuel and fenceposts, juniper might be used for chemical, fiber, or chip products such as charcoal, pulp, and particleboard. The tree crusher leaves logs in fireplace lengths, so that tree-crushed areas are popular among woodhaulers, who also remove or knock down much of the debris that would otherwise interfere with grazing animals.

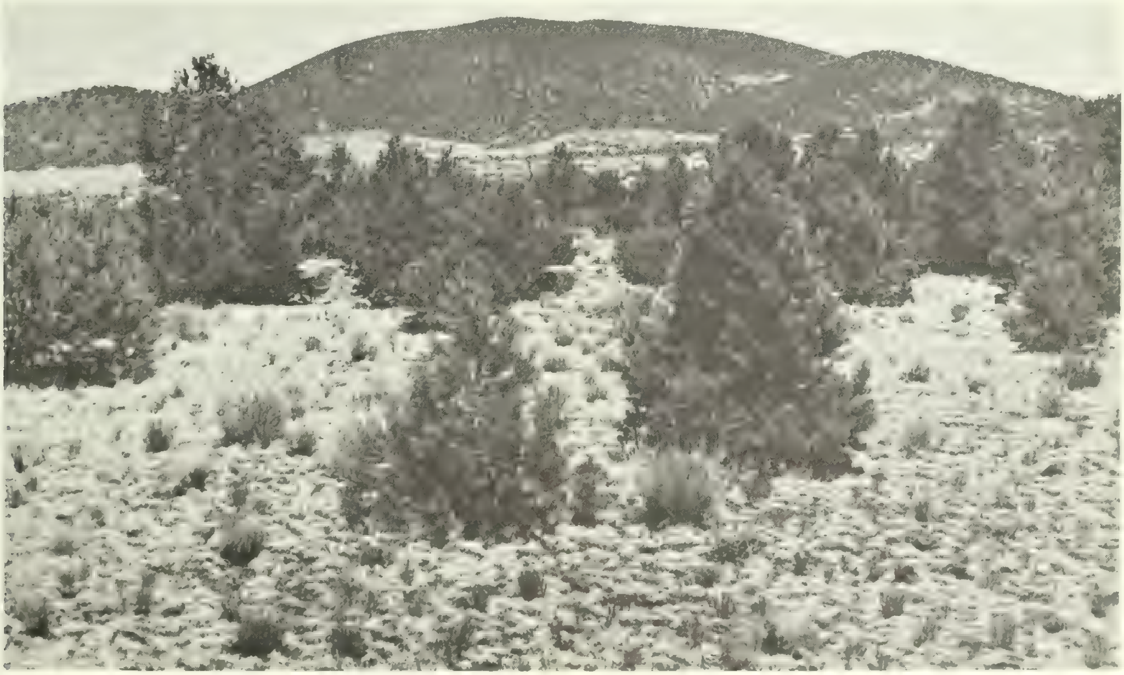

Figure 22.—Young pinyon stands often yield large numbers of desirable Christmas trees (from Barger and Ffolliott 1972).

Conclusions and Recommendations

The pinyon-juniper type in the Southwest is important because of its size, if for no other reason. It covers a significant part of Arizona and New Mexico, and has a long history of use and abuse. It has been providing people with useful products and furnishing feed for animals for centuries. As the population of the Southwest expands, pressures on the resources of the type are increasing.

In characterizing the pinyon-juniper, a rather obvious feature is its diversity. It grows under a variety of climates and on a variety of topography, parent material, and soil. The plant threads binding the communities together, of course, are the pinyon and juniper trees themselves, which grow in many different densities, proportions, and sizes.

Sufficient information is on hand to broadly characterize the major pinyon-juniper communities. Subtypes can be identified in a general way, based on species composition of the overstory. The climate has been classified, mainly for revegetation purposes. Geology and soils are known, again in a general way, and the potentials of some soils have been estimated.

The ecological information presently available is useful, but further research is warranted. A more intensive classification of the type, together with more accurate maps, is needed. From the standpoint of planning and management, it would be helpful if woodland areas were classified according to their forage-producing potential and grazing value. This would require autoecological studies of the physiology, growth habits, and reproductive characteristics of the undesirable as well as desirable species. The interrelationships among various climatic, edaphic, and other site factors as they influence plant growth need to be studied to provide bases for predicting the potentials for improving productivity.

A general problem, which overshadows many other problems, is the widespread deterioration of woodland ranges in the Southwest. The unsatisfactory conditions can be traced to the long history of overgrazing, which reduced the herbaceous ground cover and led to increased tree density. Statistics indicate National Forest woodland ranges are mostly in poor and fair condition; less than 10 percent are in good condition. Steps are being taken, however, to improve woodland range through tree control, revegetation, and systems of grazing.

Much of the available information pertaining to the Southwest's pinyon-juniper type relates to northern Arizona, due to the concentration of range research efforts there in the past. Other information stems from research in southern New Mexico at Fort Stanton, which is representative of woodland range generally more productive than those in northern New Mexico or Arizona.

Relatively large areas of pinyon-juniper in the Southwest have been neglected from the standpoint of range management research. The scope of the research likewise has been somewhat narrow in that, for most woodland ranges, we have only fragmentary information on such vital aspects of range management as proper number of animals, season of grazing, water development, fencing, salting, animal nutrition and breeding, and operational costs and returns.

General guidelines are available for judging the condition of pinyon-juniper ranges, and for management. Resting areas from grazing during the growing season at 1- to 3-year intervals has been recommended. Warm-season grasses are favored by summer deferment, while cool-season grasses respond to protection from grazing during the spring. Range readiness has been determined for pinyon-juniper ranges near Flagstaff; similar information is needed for other areas.

Summer rainfall directly affects the growth of blue grama—the most common grass on woodland ranges—but the predictive value of the relationship between precipitation and blue grama growth is uncertain. Further studies are needed to determine the possibilities of developing prediction equations as aids in estimating forage production and stocking rates in advance of the grazing season. These predictions might be made from soil moisture instead of from precipitation records.

The best use of pinyon-juniper in the foreseeable future is as range for grazing animals. If developed to their potential, pinyon-juniper ranges undoubtedly could furnish forage for more animals. The full potential of these ranges is rarely realized. In the more open stands of trees, much can be accomplished through grazing management alone; forage production can be increased substantially through deferred grazing. The denser stands support a relatively sparse understory, however, and little increase in forage can be achieved by grazing management alone; elimination of all or part of the tree overstory is necessary for significant improvement in forage production. Pinyon-juniper stands on fairly level terrain and moderately deep soils offer the best possibilities for conversion to grassland.

More information is available relating to the control of pinyon-juniper than to other aspects of management. Early attempts at cabling produced only transitory benefits; small trees missed by the cable grew rapidly, and in the end, the treated areas were a tangle of down, dead trees intermingled with a greater number of live trees than existed before cabling. Now with the experience of past failures and successes, reasonably reliable guidelines have been developed. Criteria and standards for pinyon-juniper control have been defined. Responses to control also have been studied in some detail, and situations to be avoided have been pointed out. Because of the ready availability of these guidelines, most land managers are familiar with the various methods and results to be expected. They must select sites carefully, however, and analyze characteristics of the tree stands before deciding which method to use. An increase in livestock grazing capacity of about 0.21 to 0.32 AUM per acre is indicated for the more successful pinyon-juniper conversion projects, but much lower increases are typical when conversions are attempted on sites with a low potential for improvement (Clary et al. 1974).

Guides are available for helping the land manager decide which tree stands can be optimally controlled by one of the several methods available. Factors that influence this decision are the rate at which forage is declining due to increased tree growth, the rate of forage increase expected after tree control, and the rate of change in treatment costs. The time for a given control operation is optimum when the rate of change in benefits equals the rate of change in costs. An example given by Jameson (1971) is the 1 to 3 percent optimum cover for individual tree burning.

The benefits of pinyon-juniper control have been analyzed in economic terms, but further studies are needed. Comparative cost data should be updated at 2- to 3-year intervals. Fairly thorough economic analyses are needed for representative areas to ascertain the feasibility of certain range improvement practices. Analysis of a number of pinyon-juniper conversion attempts suggest that, under 1972 economic conditions, the more successful projects just about break even from a benefit-cost standpoint (Clary et al. 1974). Projects that are less successful than the best will yield a negative net return.

Ecological evidence points to suppression of fire as a major factor influencing the spread of juniper in northern Arizona. It seems logical, therefore, that prescribed burning would be a useful tool in converting juniper stands to grassland. This has been successfully demonstrated in some areas. Burning ndividual trees has proved effective for scattered small trees. Broadcast burning of dense, mature stands requires special conditions that are hazardous. Further research on prescribed burning is warranted in view of the encouraging results obtained thus far.

A fair amount of information is available concerning species and methods for seeding pinyon-juniper ranges. Research results, however, indicate seeding woodland ranges in the Southwest is a rather risky venture. Due to wide differences among sites and highly variable weather, the best species and methods o use are uncertain. Additional research is justified to clarify some of the problems and to develop more dependable guidelines.

The importance of the pinyon-juniper as wildlife habitat is well recognized, mainly for deer, but also or elk, turkey, and other species. Overuse by heavy concentrations of deer has deteriorated some areas so hat nearly all browse plants are hedged or highlined. Competition between game and livestock is sometimes severe, particularly on ranges in poor condition. Shrub abundance is a key factor influencing the use of pinyon-juniper ranges by game animals. Recommendations for improving wildlife habitat are to control trees on the more gentle terrain (less than 15 percent slope) and deeper soil, and leave the ridges and steeper slopes untreated, especially northeast slopes. Other guidelines include keeping the cleared areas no more than ¼ mile wide, and doing minimal damage to understory browse plants. The response by deer to relatively large-scale pinyon-juniper treatments on the Beaver Creek watersheds in central Arizona has been, on the average, neutral (Clary et al. 1974). All treatments increased the production of preferred plants, but cover must be available nearby if deer are to use the areas.

Only limited information is available concerning the effects of grazing on runoff and erosion from pinyon-juniper ranges. As a general rule, heavy grazing increases soil erosion from most range types, and aggravates sedimentation problems in the Southwestern river basins. Grazing management appears to affect runoff and water yield from the pinyon-juniper type only slightly, however. The dangers of soil erosion are greatest during the early stages of conversion from trees to grass. Replacement of pinyon-juniper by grass eventually results in less soil loss, but the effects on water yield are negligible.

Coordinating the various land uses holds promise of improving the management of pinyon-juniper in the Southwest. Utilization of wood products is related either directly or indirectly to the production or recovery of the other woodland resources. For example, when trees are controlled to increase forage production, large quantities of firewood are made easily available to woodhaulers. By the same token, areas of pinyon known to be favored by local people for nut collection should be left uncleared.

In the final analysis, the evidence suggests the Southwestern pinyon-juniper type can be modified and managed for an optimum mix of products. Forage for livestock and habitat and food for wild animals are the main products, but also important are fireplace wood, fenceposts, pinyon nuts, Christmas trees, and esthetically pleasing surroundings—for recreation and living—for people. All of this can be accomplished through proper selection of conversion sites, planning, and management. The various phases of this overall program have not been sufficiently refined to permit wide application. Further research is required. But as the needs and demands intensify, models will be developed that include most of the major factors (such as climate, geomorphology, soils, crown cover and density of trees, and understory vegetation) that affect potential productivity and treatability. Then maps will be prepared delineating areas according to their potentials. The ultimate result should be wiser use and better management of the resource.

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Common and Botanical Names of Plants Mentioned
(Alphabetically by common name)

Actinea, Cooper	*Hymenoxys cooperi* Cockerell
Alfalfa	*Medicago sativa* L.
Algerita	*Berberis fremontii* Torr.
Bluestem, Turkestan (yellow)	*Bothriochloa (Andropogon) ischaemum* (L.) Keng
Burnet	*Sanguisorba minor* Scop.
Cliffrose	*Cowania mexicana* D. Don.
Dropseed, black	*Sporobolus interruptus* Vasey.
Dropseed, sand	*Sporobolus cryptandrus* (Torr.) A Gray
Galleta	*Hilaria jamesii* (Torr.) Benth.
Goldeneye, annual	*Viguiera annua* (Jones) Blake
Goosefoot, ragleaf	*Chenopodium incisum* Poir.
Grama, black	*Bouteloua eriopoda* Torr.
Grama, blue	*Bouteloua gracilis* (H.B.K.) Lag.
Grama, sideoats	*Bouteloua curtipendula* (Michx.) Torr.
Junegrass, prairie	*Koeleria cristata* (L.) Pers.
Juniper alligator	*Juniperus deppeana* Steud.
Juniper, one-seed	*Juniperus monosperma* (Engelm.) Sarg.
Juniper, Rocky Mountain	*Juniperus scopulorum* Sarg.
Juniper, Texas	*Juniperus texensis* VanMelle
Juniper, Utah	*Juniperus osteosperma* (Torr.) Little
Lovegrass, Boer	*Eragrostis chloromelas* Steud.
Lovegrass, Lehmann	*Eragrostis lehmanniana* Nees
Lovegrass, weeping	*Eragrostis curvula* (Schrad.) Nees
Mountainmahogany	*Cercocarpus montanus* Raf.
Muhly, ring	*Muhlenbergia torreyi* (Kunth) Hitchc.
Muhly, spike	*Muhlenbergia wrightii* Vasey
Muttongrass	*Poa fendleriana* (Steud.) Vasey
Oak, gray	*Quercus grisea* Liebm.
Oak, Gambel	*Quercus gambelii* Nutt.
Pine, ponderosa	*Pinus ponderosa* Laws.
Pingue	*Hymenoxys richardsonii* (Hook.) Cockerell
Pinyon, common	*Pinus edulis* Engelm.
Pinyon, Mexican	*Pinus cembroides* Zucc.
Pinyon, singleleaf	*Pinus monophylla* Torr. & Frem.
Rabbitbrush	*Chrysothamnus* spp.
Ricegrass, Indian	*Oryzopsis hymenoides* (Roem. & Schult.) Ricker
Ricegrass, little	*Oryzopsis micrantha* (Trin. & Rupr.) Thurb.
Sage, black	*Artemisia nova* A. Nels.
Sagebrush, big	*Artemisia tridentata* Nutt.
Serviceberry	*Amelanchier* spp.
Saltbush, fourwing	*Atriplex canescens* (Pursh) Nutt.
Silktassel, Wright	*Garrya wrightii* Torr.
Snakeweed, broom	*Gutierrezia sarothrae* (Pursh) Britt. & Rusby
Squirreltail, bottlebrush	*Sitanion hystrix* (Nutt.) J. G. Smith
Sumac, skunkbush	*Rhus trilobata* Nutt.
Sweetclover, yellow	*Melilotus officinalis* (L.) Lam
Threeawns	*Aristida* spp.
Wheatgrass, crested	*Agropyron desertorum* (Fisch.) Schult.
Wheatgrass, intermediate	*A. intermedium* (Host) Beauv.
Wheatgrass, western	*A. smithii* Rydb.
Wheatgrass, pubescent	*A. trichophorum* (Link) Richt.
Wildrye, Russian	*Elymus junceus* Fisch.
Wolftail	*Lycurus phleoides* H.B.K.

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The pinyon-juniper type, characterized by diversity of climate, soils, and topography, covers about 30 million acres in Arizona and New Mexico. The major problem is widespread deterioration of the range resources due to overgrazing and increases in tree density. General guidelines are available for judging the condition and grazing management of pinyon-juniper ranges, as well as for deciding where and how to control the trees for range and wildlife habitat improvement. Although further research is warranted, information is adequate to modify and manage the type to provide an optimum mix of products. These include forage for livestock, and food and habitat for wild animals as the main products; also included are fireplace wood, fenceposts, pinyon nuts, and Christmas trees.

Keywords: Range management, pinyon-juniper type, forage, tree control, *Pinus* sp., *Juniperus* sp.

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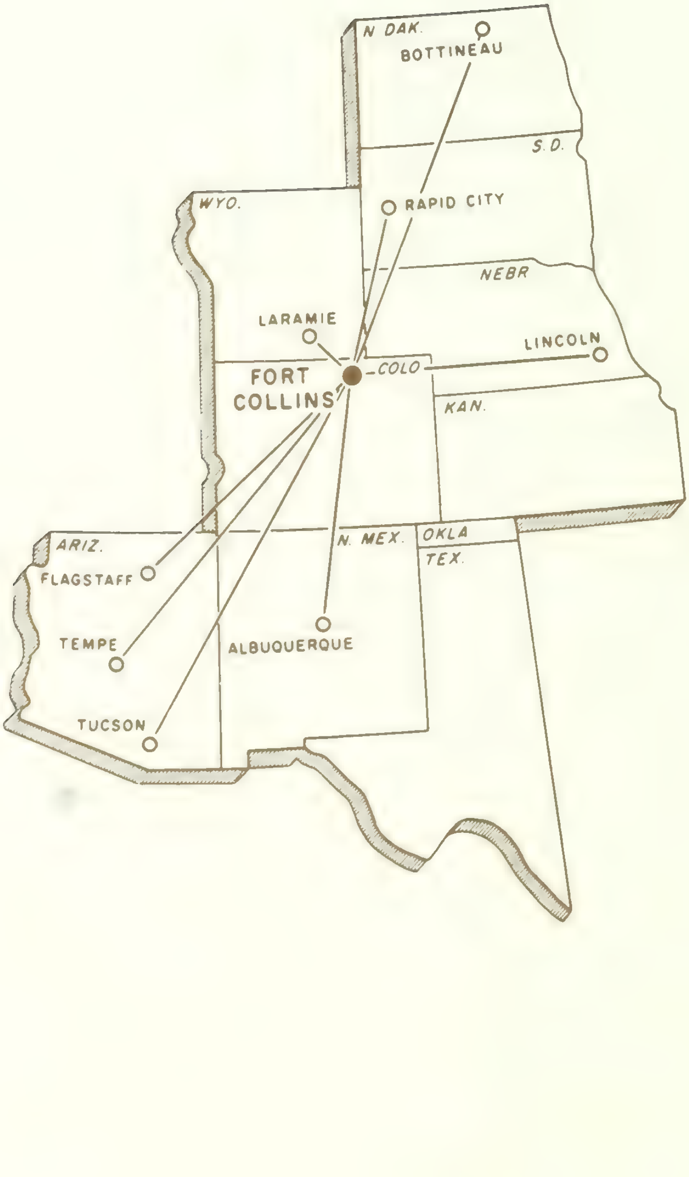
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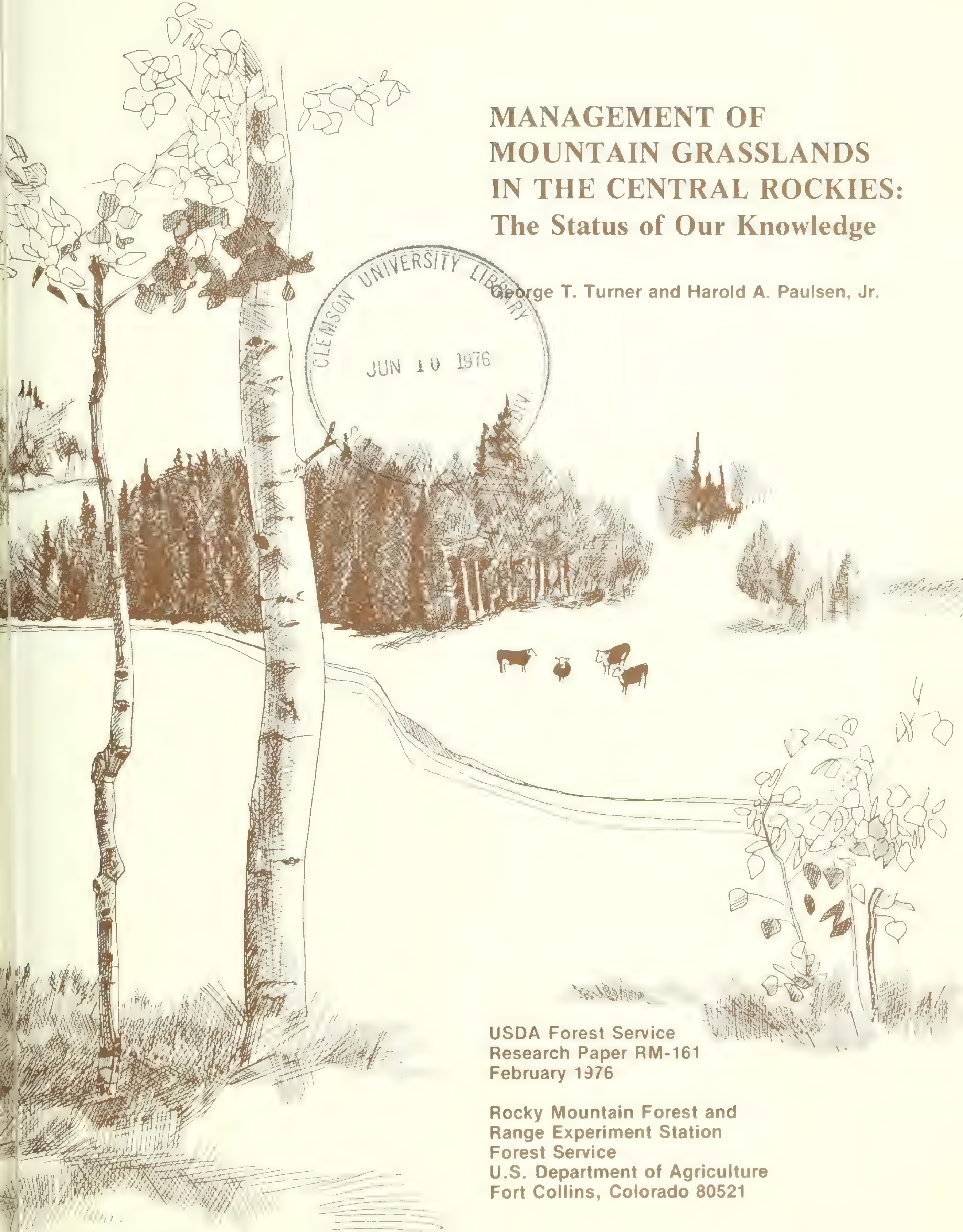

MANAGEMENT OF MOUNTAIN GRASSLANDS IN THE CENTRAL ROCKIES:

The Status of Our Knowledge

George T. Turner and Harold A. Paulsen, Jr.

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February 1976

Rocky Mountain Forest and
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Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Turner, George T., and Harold A. Paulsen, Jr.
1976. Management of mountain grasslands in the central Rockies: The status of our knowledge. USDA For. Serv. Res. Pap. RM-161, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Mountain grasslands provide important summer grazing for livestock and big game. Knowledge is generally adequate for proper grazing management of these grasslands, but management and improvement costs tend to be relatively high because of their remoteness. Suggested improvements to increase range usability, improve forage production, and control livestock must be coordinated with water and timber production, and wildlife and recreation needs.

Keywords: Range management, mountain grasslands, subalpine forest ranges.

USDA Forest Service
Research Paper RM-161

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MANAGEMENT OF MOUNTAIN GRASSLANDS IN THE CENTRAL ROCKIES:

The Status of Our Knowledge

George T. Turner and Harold A. Paulsen, Jr.
Principal Range Scientists
Rocky Mountain Forest and Range Experiment Station[1]

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[1] *Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University. Turner is now retired; Paulsen is Assistant Director for Planning and Application.*

Contents

Page
INTRODUCTION 1
PHYSICAL ENVIRONMENT 2
  Climate 2
  Geology and Soils 3
  Vegetation 3
  Common Fauna 4
  Plant Development 4
  Herbage Production 5
  Plant Succession 5
  Range Condition 8
CURRENT RANGE USES AND RANCHING OPERATIONS 9
RANGE MANAGEMENT PRACTICES 10
  Proper Grazing 10
  Kinds of Animals 10
  Number of Animals 11
  Season of Grazing 11
  Grazing Systems 11
  Improving Forage Production 13
    Seeding 13
    Noxious Plant and Animal Control 13
    Fertilizing the Range 14
    Water Spreading 15
    Controlled Burning 15
  Increasing Range Usability 15
  Managing the Livestock 16
LIVESTOCK GRAZING AND OTHER USES 16
  Water and Timber Production 16
  Wildlife and Recreation 17
EMERGING DEMANDS FOR THE RESOURCE 18
LAND MANAGEMENT PROBLEMS AND RESEARCH NEEDS 19
LITERATURE CITED 19
COMMON AND SCIENTIFIC NAMES OF PLANTS AND ANIMALS MENTIONED OR FOUND IN THE MOUNTAIN GRASSLANDS 23

MANAGEMENT OF MOUNTAIN GRASSLANDS IN THE CENTRAL ROCKIES:
The Status of Our Knowledge

George T. Turner and Harold A. Paulsen, Jr.

INTRODUCTION

Management of mountain grasslands, as with lower elevation ranges of western United States, has evolved since the early 1900's from concerns voiced as to depleted ranges, erosion, excessive livestock numbers, and lack of management. Pioneer range managers and range researchers initiated practices and installed studies to gain understanding of the resource, and curtail its widespread destruction. Since these early days, the basic principles and strategies of range management have developed that provide the contemporary land manager with necessary tools for wiser use of the resource. Many are commonplace technology to today's range manager, but they stem from far-reaching fundamental research, empirical studies, and years of experience.

This publication summarizes information from these sources. Its purpose is to provide a resumé of the published literature and accepted practices pertinent to the management of mountain grassland ranges of the central Rockies, and to identify gaps in existing knowledge that handicap the range manager in meeting his multiresource responsibilities.

Mountain grasslands of the central Rockies are closely associated with the subalpine forests in Wyoming, Colorado, New Mexico, and Arizona (fig. 1). The forest types commonly occur at elevations between 8,000 and 11,500 feet, or between the upper

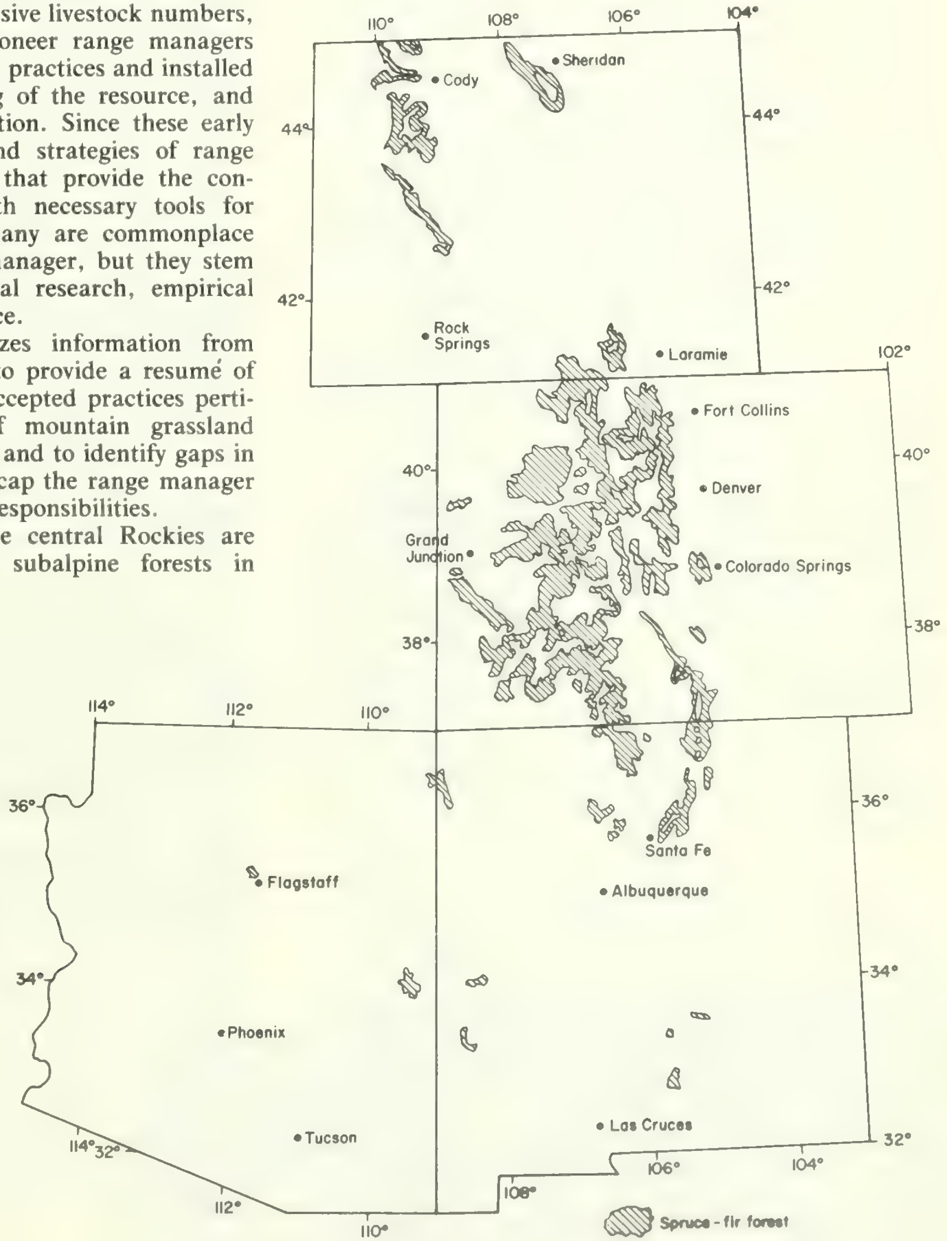


Figure 1.—Spruce-fir forests of the central Rockies within which are intermingled mountain grasslands.

limits of the ponderosa pine[2] forests and timberline. Within the timber stands, mountain grasslands are interspersed as parklike openings that vary in size from a few to several thousand acres (fig. 2). The grasslands may be found on gentle to steep slopes, wide valleys, and broad, rounded ridges. Commonly their distribution and major physical characteristics are described on the basis of the more extensive forest types.

The region offers a multiplicity of resource products as well as less tangible values that center around its outstanding recreation-related attributes. Increasing utilization of its timber, skyrocketing demand for ski facilities, growth of new homes and communities, and expansion of water storage and transfer systems have become prominent concerns for the land manager and planner. Moreover, the traditional uses such as livestock operations and mining continue to be important elements in local and regional economies.

The subalpine forests of the central Rockies include lodgepole pine, quaking aspen, and Engelmann spruce-subalpine fir types as mapped by Küchler (1964). Frequently referred to as spruce-fir forests, they occupy about 15 million acres in the four-State area, with approximately 72 percent in Colorado, 16 percent in Wyoming, 11 percent in New Mexico, and 1 percent in Arizona. Of this area, grasslands probably comprise about 1½ million acres.

The spruce-fir type in Wyoming occurs mainly in the northern portion—on the Big Horn, Absaroka, and Wind River Mountains. From the Medicine Bow mountains in southern Wyoming, it extends southward almost continuously along the Continental Divide and through western Colorado into northern New Mexico. Elsewhere in New Mexico and in Arizona, it is limited to relatively small, widely separated areas at high elevations. Because the subalpine zone is most extensive in Colorado, the discussion pertains primarily to mountain grasslands of that area.

Mountain grasslands in the central Rockies were first grazed by domestic livestock about 100 years ago. The region lacked transportation, was remote from population centers, and was occupied by various tribes of Indians, all of which affected early settlement. Following the discovery of gold and silver in the mid-1800's, Indians were moved to reservations, railroads were built to serve the region, and settlement proceeded rapidly.

Large numbers of cattle were brought in to graze the lower, more accessible ranges. Those ranges soon were overstocked, and the demand increased for forage at higher elevations. Bands of sheep were brought in somewhat later than cattle. Range wars broke out as stockmen fought to retain their "rights" to graze lands of the open, Federal domain. By 1900, practically all grazable land was being grazed, and much had already been overgrazed. Maximum use occurred about 1918 to meet wartime demands.

Regulation of grazing on the higher rangelands began with the establishment of National Forests in the early 1900's. Specific areas were allotted to individual ranchers or groups of ranchers, and permits were issued which allowed them to graze specific numbers and kinds of livestock for specified periods. Present use of National Forest rangeland in the West is only about 25 percent of what it was at one time. Much of the reduction has resulted from a decline in sheep numbers and shortening of the grazing season (USDA Forest Service, unpublished data).

PHYSICAL ENVIRONMENT

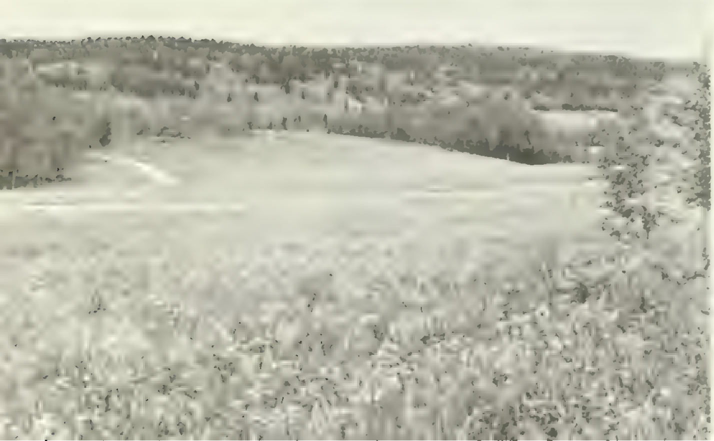
Climate

The general climatic regime is typical of subalpine forests, and is broadly characterized by cold winters and relatively cool summers. Although far inland from the Pacific Ocean and the Gulf of Mexico, the higher elevations receive rather large amounts of precipitation in comparison to the adjacent valley lowlands. Winter storms that move inland from the Pacific lose much of their moisture before reaching the central Rockies; relatively more precipitation falls on the Western Slope than east of the Continental Divide.

Long winters, deep snow, and short growing seasons characterize the climate of mountain grasslands. Average annual precipitation varies from 20 to 40 inches. Snow accounts for 50 to 75 percent of the total. The ground frequently is snow covered from October until May, and the snowpack commonly attains a depth of 6 feet.

Winter temperatures often reach subzero levels, especially in January and February. However, surface soil temperatures under a deep snowpack are usually not much below 32°F. Under such conditions, some plants remain green throughout the winter, and others begin growth while the ground is still snow covered.

Figure 2.—Mountain grassland parks occur intermixed with high-elevation forests.



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[2] Common and scientific names of plants and animals mentioned or found in the mountain grasslands are listed at the end of this paper.

Snowmelt during a 2- or 3-week period in April or May usually saturates the soil mantle (fig. 3). Ample soil moisture and rapidly rising temperatures following snowmelt promote rapid plant growth.

Rainfall in June tends to be low west of the Continental Divide and relatively high east of the Divide. Thunderstorms in July and August are common throughout the region. Although monthly rainfall varies widely from year to year, total amounts from June through September range from about 6 to 10 inches.

Temperatures during summer months are cooler at the higher elevations and upper latitudes. At intermediate locations, the growing season usually extends from June through August. Even then, frost occurs occasionally. During July and August, temperatures average about 50° to 55°F; seldom do they exceed 75° or 80°F. Killing frosts, usually early in September, soon are followed by fall snowstorms.

Geology and Soils

Geology of the Rocky Mountains is extremely complex. The present Rockies were formed after older mountain ranges had been nearly leveled by erosion, leaving thick deposits of sediment. As upheaval was renewed, most of the overburden was again eroded away, but some remained as peneplains, fault blocks, remnants of folded structures, or irregular masses of metamorphic rock. As the Rockies continued to rise, underlying intrusive igneous rocks became widely exposed along the central axis, especially at the higher elevations. Much of the eroded material was redeposited to form the Colorado Plateau west of the mountain chain and the Great Plains along the eastern slopes.

Concurrent with and following uplift of the mountains, volcanic materials were extruded at scattered locations. Some deposits, such as those in southwestern Colorado and northwestern Wyoming, are deep and extensive; others occur locally in thin mantles. As a group, igneous materials underlie equally as much of the land surface as sedimentary rocks in the subalpine zone.

Landscape of the Rockies has been modifed more recently by glaciers and swift-flowing streams. In the upper part of the subalpine zone near timberline, alluvial deposits are common. At lower elevations, streams have cut a network of valleys and steep-walled canyons, especially in the plateaus of western Colorado. Valleys are sharply incised between mesas capped with erosion-resistant materials. Where soft shales are exposed, a hilly terrain has developed. Occasional landslides in those areas continue to alter the landscape.

Soils of the region are as variable as the parent materials from which they were derived and the conditions under which they developed. Cool to cold temperatures, relatively abundant moisture, and the dominant coniferous forest vegetation have favored the formation of podzolic soils on most high mountain areas. In the intermingled parks and open treeless slopes or ridges, grassland soils have developed. They generally resemble prairie soils in that the A-horizon is usually dark brown, relatively high in organic matter content, and slightly acid, with little, if any, lime accumulation. Although a clay pan is present in some areas, most mountain grassland soils are well drained. Fertility and productivity vary with soil parent materials, soil depth, and other factors of the local environment. Several soil series may be present within local areas (Retzer 1962, Smith 1969b). Much work is needed to identify, describe, and correlate characteristics of mountain grassland soils as a basis for determining land capabilities and making sound management decisions.

Vegetation

Mountain grassland vegetation is a continuum expressing many interacting factors of the local environment. Most grasslands support, or are capable of supporting, numerous kinds of perennial grasses and forbs. Annual plants seldom are abundant except on recently disturbed or severely overgrazed areas.

Two major but intergrading plant communities comprise the bulk of the mountain grassland type. Most extensive is the mountain bunchgrass community characterized by Thurber fescue, where that plant has not been eliminated by grazing. The range of Thurber fescue extends from southern Wyoming southward through Colorado into northern New Mexico. The Wyoming bunchgrass community occurs mainly in Wyoming, but fingers southward in northern Colorado. It is typified by Idaho fescue, which is

igure 3.—Runoff during snowmelt on Black Mesa, western Colorado.

commonly associated with bluebunch wheatgrass and sagebrush (mainly big sagebrush) at lower elevations and on the drier sites (Williams 1963).

Other grasslands are found in the high-elevation, broad valley floors between major mountain ranges in central and southern Colorado. Species are often an admixture of elements from lower ranges with those of the higher and somewhat more mesophytic dry mountain meadows (Costello 1944).

On more moist sites, wet meadow communities occur throughout the major plant communities. Sedges dominate these areas, but tufted hairgrass, Kentucky bluegrass, and alpine timothy are frequently abundant together with a number of moisture-loving forbs.

Vegetation varies greatly. Conspicuous and distinct differences between plant communities frequently accompany marked changes in soil texture or exposure. Differences are less conspicuous with gradual changes in elevation or other features of the environment.

Mountain grasslands occupy sites where soils tend to be finer textured, deeper, and less well drained than on adjacent forested areas. Tree growth apparently is precluded from grassland areas because of competition from herbaceous plants, low temperatures, soil heaving, poor drainage, or other limiting factors. Where grasslands intermingle with timbered areas on hillsides, differences in site characteristics are usually less pronounced and trees are more likely to invade.

Under pristine conditions, Thurber fescue or Idaho fescue evidently comprised much of the vegetation, lending a grassland aspect to many high mountain parks. Forbs doubtless were locally abundant and conspicuous on recently disturbed sites. Within the subalpine zone, forbs tend to be more prominent at higher elevations and shrubs at lower elevations. A grassy understory commonly is overtopped by big sagebrush on relatively dry sites and by silver sagebrush on more mesic sites at upper elevations. Gambel oak and associated shrubs frequently comprise part of the plant cover on grasslands near the lower limit of the subalpine zone in Colorado.

Some of the other more common plants and their relative contribution to plant cover on relatively undisturbed grasslands are listed in table 1. Vegetative cover on the Colorado sites was described by Turner and Dortignac (1954) as "dense Thurber fescue." That in Wyoming was considered by Hurd (1961) to be representative of grasslands little used by livestock.

Several hundred plant species from mountain grasslands have been identified and described, including their general range and distribution (Coulter and Nelson 1909, Harrington 1954, Dayton 1960, Johnson 1964, Hermann 1966). However, local distribution, abundance, and ecologic relationships of many are not well known.

Table 1.--Plants commonly present on relatively undisturbed mountain grasslands in Colorado and Wyoming, and their relative contribution to vegetative cover

Colorado sites (4)		Wyoming sites (9)	
Species	Percent	Species	Percen
GRASSES AND SEDGES:		GRASSES AND SEDGES:	
Brome, mountain	2	Brome, pumpelly	4
Fescue, Idaho	5	Bluegrass, Sandberg	3
Fescue, Thurber	46	Fescue, Idaho	25
Needlegrass	2	Junegrass, prairie	3
Sedges	1	Needlegrass, subalpine	4
Wheatgrass, slender	1	Sedge. needleleaf	8
Other grasses	1	Spikefescue	3
Total	58	Wheatgrass, slender	3
		Wheatgrass, thickspike	2
FORBS:		Other grasses and sedges	8
Agoseris, pale	4	Total	63
Cinquefoil	2		
Dandelion, common	3	FORBS:	
Fleabane, aspen	6	Agoseris, pale	4
Geranium, Fremont	7	Avens	4
Peavine, aspen	3	Bedstraw, northern	2
Sneezeweed, orange	4	Lupine, silky	6
Yarrow, western	5	Yarrow, western	[illegible]
Other forbs	7	Other forbs	17
Total	41	Total	35
Other plants	1	Other plants	2
Total	100	Total	100

Common Fauna

Mountain grasslands are rich in fauna, the number of genera and species being proportional to the number of habitats (Hall and Kelson 1959). Because local climate, soils, and vegetation associated with grasslands and adjacent forests are diversified, various habitats characterize the subalpine zone.

Of the larger animals, mule deer are most abundant. They range throughout the type during the snow-free period. Elk are locally common, and at upper elevations may utilize grasslands more intensively than deer. Pronghorns occur in small bands in some of the large mountain parklands, and moose browse in wet meadows and along stream bottoms in Wyoming. Bighorn sheep, black bears, and mountain lions make casual use of grasslands.

Various birds, rodents, and other small mammals may be relatively important because of their wide distribution, occasional abundance, and influence on mountain grasslands.

Reptiles are scarce on mountain grasslands, the principal one being the garter snake (Yocum and others 1969). Salamanders, toads, and frogs are somewhat more common.

Plant Development

Most herbaceous plants begin growth in spring soon after snow disappears. The leaves of some, such as elk sedge, Gabriel's trumpet, and rock jasmine, remain green throughout the winter. Thurber fescue produces new but chlorotic leaves while still under the snowpack. As temperatures rise following snowmelt, plant growth accelerates. However, some species develop faster than others, and the floral display changes continually during late spring and summer.

Early-blooming plants include fawn lily, spring beauty, greenleaf bluebell, and low larkspur. These plants mature and generally disappear by early summer. Mutton bluegrass is one of the earlier maturing grasses.

Typical of plants that bloom 6 to 8 weeks after snowmelt are mountain brome, Idaho fescue, western yarrow, orange sneezeweed, Fremont geranium, and Gabriel's trumpet. Species that bloom later include hairy goldaster, agoseris, and Parry rabbitbrush.

Plant development varies from year to year as well as with the microclimate of local sites (fig. 4). At high elevations, growth begins later but stages of development tend to be shorter than at low elevations; plants thus complete their life cycle in a relatively short period (Costello and Price 1939, Pond and Smith 1971). Temperature and moisture during the growing season, of course, influence the rate of development.

Range readiness also varies considerably, since development of the forage crop to a stage suitable for grazing depends on when the snow disappears and ensuing temperatures (Costello and Price 1939). According to guidelines of the USDA Forest Service (1962), most ranges are ready for grazing between mid-June and mid-July. However, when the snowpack is unusually deep and slow in melting, the grazing period may begin even later.

Floral aspects of mountain grasslands differ markedly from one year to another. Production of viable seed by individual plant species probably varies even more. For example, culms of Idaho fescue were produced in abundance only twice during a 5-year period in Wyoming (Pond and Smith 1971). Erratic production of seedstalks also has been observed on Black Mesa in Colorado over an 18-year period. Even though collected during two relatively good "seed years," seed of Idaho fescue germinated at an average rate of less than 10 percent. The inconsistency of grass seed production often has not been fully recognized in the development of grazing systems intended to provide for natural seeding of important range grasses.

Herbage Production

Herbage production on mountain grasslands occasionally exceeds 3,000 pounds per acre; however, yields of 1,000 to 2,000 pounds are much more common (Turner and Dortignac 1954, Hurd 1961). Above-average yields are produced on deep, fertile soils at intermediate elevations during years of favorable growing conditions. Highly productive sites may support a relatively dense cover of bunchgrasses, although some produce large yields of tall forbs (fig. 5). A variable mixture of grass and forb herbage is characteristic of mountain grasslands. Browse (mainly sagebrush or rabbitbrush) may be locally abundant.

Herbage production and composition vary considerably from year to year. During an 11-year period in which production on moderately grazed pastures in western Colorado averaged 1,456 pounds per acre (Paulsen 1969), yields ranged from 23 percent above to 27 percent below average. During that period, grasses contributed as little as 35 percent and as much as 62 percent to the total herbage. Although such variability is readily apparent, the underlying causes are obscure.

Peak development (maximum standing crop) of herbage is reached between mid-July and mid-August, after which weight of the biomass declines. If rainfall is adequate and well distributed, Kentucky bluegrass remains green throughout the summer and produces considerable regrowth after being grazed. Idaho fescue and other bunchgrasses produce little regrowth if grazed when past the vegetative stage (Pond and Smith 1971).

Plant Succession

Successional stages of mountain grassland vegetation are similar to other grasslands, except for kinds of plants present. With misuse, the more palatable plant species are replaced by less palatable ones better adapted to the altered environment; desirable perennial plants may be eliminated from the plant cover. These "stages" correspond in general to those described by Sampson (1923) as (1) climax herbaceous; (2) mixed grass and weed; (3) second or late weed; and (4) first or early weed stage.

In reality, plant successional stages are indistinct and variable. Floristic composition varies with site characteristics, forage preference and use by grazing animals, and other environmental influences. Because the factors that influence floristic composition and plant succession are complex, changes in prominence of individual plant species seldom can be interpreted with certainty on the basis of present knowledge. In general, however, nonpalatable forbs or shrubs tend to replace palatable grasses on mountain grasslands grazed by cattle, and grasses tend to replace the more palatable forbs on ranges grazed by sheep.

Because of the competitive advantage that nonpalatable or less preferred plants have on grazed range, discontinuance of grazing may serve only to retard or prevent further range deterioration; it may not shift competitive advantage to palatable plants. Consequently, well established, deep-rooted plants (such as Parry rabbitbrush) that are unpalatable and

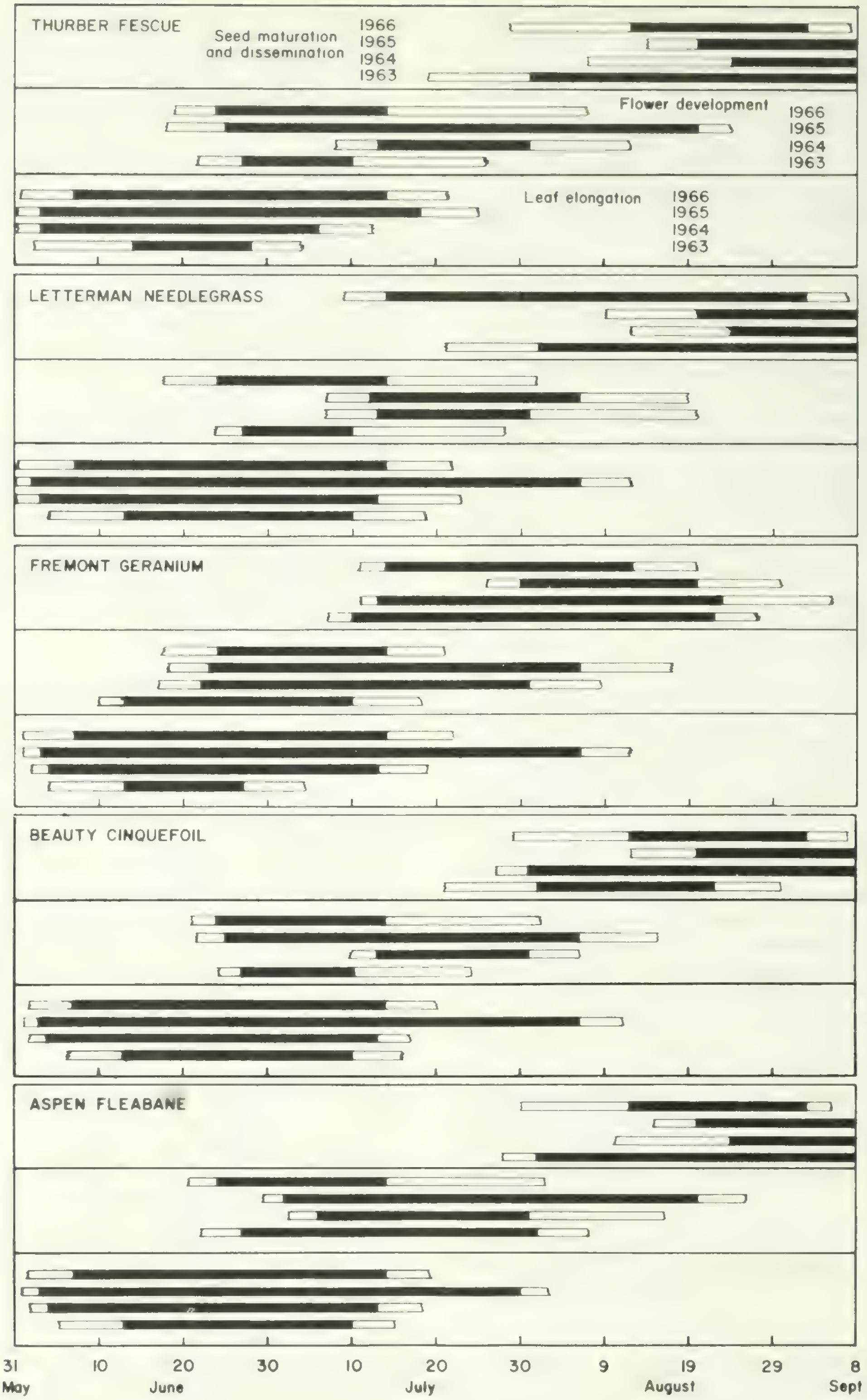

Figure 4.—Periods of leaf elongation, flower development, and seed maturation and dispersal of five species on Black Mesa, western Colorado. Open and irregular ends of the bars indicate dates for initiation and cessation of a phenological stage were indefinite (from Paulsen 1970b).

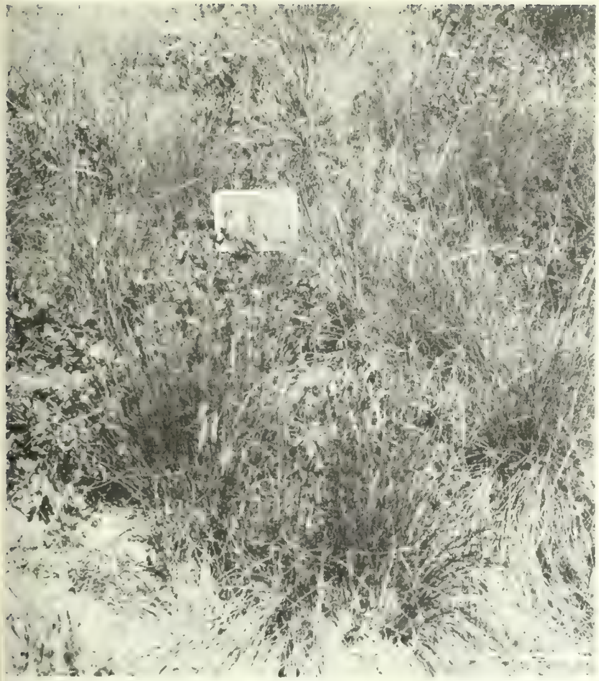

Figure 5.—Thurber fescue-forb cover, Black Mesa Experimental Range, western Colorado (from Paulsen 1970b).

locally abundant on Thurber fescue grassland may persist for years, regardless of grazing management.

On Black Mesa in western Colorado, plant cover on an area of Thurber fescue grassland protected from grazing for 8 years (Paulsen 1970b) remained generally unchanged: the grass-forb composition in 1962 was 62 percent grass versus 38 percent forbs; in 1969, 65 percent grass versus 35 percent forbs. Idaho fescue and Letterman needlegrass have remained prominent on Black Mesa under moderate grazing and occasional heavy use, but Thurber fescue has declined. The success of Thurber fescue on the experimental plots on Black Mesa (Paulsen 1970b) was attributed to its early and vigorous growth habit, abundant seed production, and successful seedling establishment. This species rapidly dominated the plots where forbs were removed from the plant cover.

Range deterioration is often characterized by changes in addition to the relative prominence of individual plant species. In early stages on cattle ranges, forbs or secondary grasses usually increase as primary grasses decrease. Total cover may change very little, and occasionally may increase. Herbage production and litter may decrease slightly; bare soil tends to increase. In more advanced stages of deterioration, reductions in ground cover and herbage yields become pronounced (Turner and Dortignac 1954, Klemmedson 1956). The aspect changes to that of forbs or shrubs, bare soil usually is conspicuous, and signs of runoff and erosion may become evident. With reduction in cover, the seedbed becomes more favorable for reproduction of certain plant species and less favorable for others.

Less evident, but equally important, are changes in the microenvironment and site characteristics that accompany range deterioration. With less ground cover (live and dead material), surface soil temperatures rise faster in the spring and continue higher throughout the summer. Although initial growth of plants may be accelerated, soil moisture is depleted through evaporation and contributes less to plant growth. Soil organic matter likely will be oxidized more readily (Albrecht 1938), affecting kinds, abundance, and activity of soil organisms. Eventually, soil fertility and productivity are reduced.

Pocket gophers and other small animals also influence floristic composition and the microenvironment. On Grand Mesa in western Colorado, available herbage was reduced by 20 percent or more where gophers numbered 25 to 30 per acre (Turner 1969). They may substantially reduce ground cover and may be the primary cause for the exposure of bare soil (Ellison 1946, Turner and others 1973). Gopher effects on infiltration, runoff, soil erosion, and moisture content of the soil vary with local conditions. On many areas their burrowing activity has resulted in mixing of soil horizons, and much vegetation has been covered by the soil they excavated (Ward and Keith 1962). Other studies of mountain grassland and aspen communities, however, have indicated gophers performed a useful function through cultivating and aerating the soil without reducing total herbage production (Ellison and Aldous 1952).

Control of pocket gophers may result in increased abundance of certain animals and decreased abundance of others. With thinning of ground cover, the habitat may become more suitable for deer mice but less favorable for montane voles (Larrison 1942, Tester and Marshall 1961). Activities of these and other small animals, including birds and insects, may markedly influence the amount, kind, and disposition of plant seed.

Often, however, responses caused by rodent activities cannot readily be distinguished from effects of livestock grazing and weather. Influences of fire, soil erosion, phytotoxins (allelochemicals), and soil nutrients also complicate understanding of the composition and succession of mountain grassland vegetation (Ellison 1949, Miller 1963, U.S. Natl. Comm. Int. Biol. Program 1971, Wright 1971).

On Colorado ranges that are grazed too heavily by cattle, Thurber fescue commonly is replaced by Idaho fescue and associated bunchgrasses on relatively coarse-textured soils, and by Kentucky bluegrass on fine-textured or compacted soils. Western wheatgrass and mulesear sometimes occur on fine-textured soils along with or instead of Kentucky bluegrass (Turner and Dortignac 1954). Moir (1967) reported similar findings for Kentucky bluegrass on fine-textured soils in southern New Mexico.

Forbs such as common dandelion, Fremont geranium, and aspen fleabane frequently become more abundant with grazing, and sometimes replace the secondary grasses. More commonly, however, these plants, along with mountain brome, slender wheatgrass, Letterman needlegrass, western yarrow, orange sneezeweed, aspen peavine, and herbaceous cinquefoils occur in various mixtures (Klemmedson 1956; Paulsen 1969, 1970a). Big sagebrush and Parry rabbitbrush tend to increase with overgrazing on some sites.

In Wyoming, Idaho fescue and other common components of relatively undisturbed grasslands, such as thickspike wheatgrass, slender wheatgrass, bluebunch wheatgrass, pumpelly brome, inland bluegrass, pale agoseris, and silky lupine, become less prominent under grazing pressure. Tending to replace them are needleleaf sedge, prairie Junegrass, big bluegrass, Canby bluegrass, Cusick bluegrass, Sandberg bluegrass, subalpine needlegrass, avens, starry cerastium, and western yarrow (Hurd 1961, Williams 1963).

On mountain range near Bozeman, Montana (Branson and Lommasson 1958), where improved management included lighter grazing, percentages of herbage yields contributed by individual species changed noticeably. This range, which varied in elevation from 6,100 to 7,500 feet, formerly had been overgrazed by sheep and cattle. From 1932 to 1955, grass yields increased from 32 to 47 percent of the total herbage, while forb yields decreased from 68 to 52 percent. Prominent species that increased were mountain brome (*Bromus marginatus* in list of plant names), timothy, and Kentucky bluegrass; those that decreased were slender wheatgrass, Idaho fescue, starry cerastium, sticky geranium, and cinquefoil. Certain species apparently respond differently to grazing or to release from grazing, depending upon local circumstances.

Range Condition

Range condition, defined as "the current productivity of a range relative to what that range is naturally capable of producing" (ASRM-Range Term Glossary Comm. 1974), commonly considers vegetation, litter, and surface soil (Hanson 1951, Parker 1951). Rangeland that is influenced little, if at all, by livestock provides the standard for classifying condition, which is ordinarily expressed in relative terms such as excellent, good, fair, or poor. Ratings are made through use of score cards developed for specific sites (Dyksterhuis 1949), or major plant communities (USDA-FS 1962). Different criteria are used for sheep range than for cattle range.

Range condition classification may not provide a reliable guide to grazing capacity, and may not necessarily indicate condition relative to the management goal. For example, dense stands of Thurber fescue produce much herbage and provide excellent watershed cover (Turner and Dortignac 1954), but often produce relatively less forage than associated grasses because of its coarseness. Certain forbs contribute appreciably to the quantity and quality of forage on these ranges (table 2) (Paulsen 1969). Pocket gophers also influence range condition of mountain grasslands (Moore and Reid 1951, Ellison and Aldous 1952, Turner 1969).

Table 2.--Production, cattle preference, and relative forage value for forage species on mountain grassland ranges, Black Mesa Experimental Forest and Range, Colorado (from Paulsen 1969)

Species	Production	Utilization by number of days grazed				Forage value[1]
		18	36	56	78	
	[illegible]	*Percent*				
GRASSES AND GRASSLIKE:						
Idaho fescue	222	5	8	15	38	1.00
Letterman needlegrass	126	3	4	8	32	.47
Thurber fescue	119	4	7	12	28	.39
Bromegrass	51	6	9	14	38	.24
Slender wheatgrass	55	7	12	15	36	.22
Kentucky bluegrass	7	13	10	31	46	.04
Others	55					
FORBS:						
Aspen fleabane	90	3	12	25		.26
Aspen peavine	65	3	6	10		.07
Agoseris	33	11	13	17		.07
False sunflower	9	9		44		.05
Goldenrod	11	1		18		.02
Dandelion	16	8	8	10		.02
Sharpleaf valerian	11	1	6	14		.02
Others	500					

[1] Ranking based upon the product of final utilization and production divided by the product obtained for Idaho fescue Species listed were present on at least 5 percent of the plots.

Although the condition of mountain grassland can be evaluated on the basis of predetermined standards, trends in condition are much more difficult to determine. Vegetation and ground cover change in response to combined environmental influences, both seasonally and long-term. Most commonly considered in estimating trend are: (1) changes in relative abundance of plants preclassified according to their desirability or expected response to grazing; (2) plant vigor, usually expressed through number and height of grass flower stalks or length of leaves; and (3) soil stability, as evidenced by litter accumulation, surface runoff, and erosion (Parker 1951). Other factors sometimes considered are changes in size of grass clumps, abundance of seedlings or young plants, frequency of dead or dying plants, arrangement of plant colonies, amounts of forage produced, and current degree of grazing (Talbot 1937, Reid and Pickford 1946, Ellison 1951, Humphrey 1955). Under proper grazing with upward range trend, ground cover usually will reach or maintain a level sufficient to prevent excessive erosion, soil nutrients will be recycled in amounts necessary to maintain soil fertility, and soil structure conducive to growth of forage plants will be maintained.

Long-term effects of grazing on chemical, microbiological, and physical characteristics of the soil are not well documented. Although most mountain grassland soils contain relatively large amounts of organic matter, the supply of available nutrients varies with soil acidity and parent material, abundance and activity of micro-organisms, and other factors (table 3). Soil structure normally is maintained by natural processes if the range is grazed when the ground surface is dry and firm. Organic matter tends to maintain a desirable soil structure by reducing or counteracting compaction (Lull 1959).

CURRENT RANGE USES AND RANCHING OPERATIONS

High-altitude rangelands are essential to the operation of many livestock ranches in the central Rockies, since their summer production rounds out the annual forage requirements. Hay grown under irrigation in the valleys provides winter feed for cattle; lower elevation rangelands, irrigated pastures, and crop aftermath may sustain the livestock during spring and fall months. Many sheep winter on semidesert shrub ranges, some of which are far from summer ranges. Sheep are commonly trucked from winter to spring range, and occasionally to summer range. If not, they are herded from range to range as the forage reaches a state of range readiness.

Mountain grasslands usually are grazed more heavily by cattle than are the interspersed aspen and shrub ranges. Sheep more commonly graze lands occupied by shrubs and trees, particularly within the aspen type. Few ranges are grazed by both sheep and cattle. Use of mountain grasslands by horses is expected to increase with increased use of the subalpine zone for recreational purposes.

In 1970, 2,763 permits were issued for grazing of summer range within National Forests of the Rocky Mountain Region. On an animal-unit basis, the cattle permitted outnumbered sheep about four to one.

Monetary value of forage supplied by mountain grasslands cannot be estimated accurately, partly because information is lacking on the extent of the grasslands and the values contributed by associated types that are grazed concurrently. Grazing values are indicated, however, by 1970 records that show that National Forest ranges in the Rocky Mountain Region (mainly Colorado and most of Wyoming) supplied forage for 1,110,627 animal-unit months (AUM)[3] of grazing from mid-June to mid-October. Computed at $3 per AUM, the annual grazing value exceeded $3 million. The livestock operations that utilize the high-altitude ranges are often the mainstay of the economy and welfare of local communities.

Higher costs inherent in management and improvement of range and livestock, including salaries for range riders, fencing, water development, noxious plant control, and range reseeding, however, substantially reduce the economic attractiveness of grazing mountain rangelands. Profits may be further reduced by relatively high losses of livestock grazing these remote ranges. For example, on National Forests of the Rocky Mountain Region, death losses from poisonous plants, predators, and other causes in 1970 amounted to 1.5 percent of the cattle and 3.8 percent of the sheep being grazed; monetary value of these animals probably exceeded $1 million.

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[3] *An animal-unit month is defined as the amount of feed or forage required by an animal unit (usually considered to be one mature cow with calf or their equivalent) for one month.*

Table 3.--Analyses of the less than 2 mm fraction of soils from the Black Mesa Study Site[1] (from Paulsen 1970b)

Slope position and depth	Texture			Moisture-holding capacity		Organic matter	Lime	Nitrogen	pH	Phosphate (P_2O_5)	Potassium (K_2O)
	Sand	Silt	Clay	1/3 atm	15 atm						
	Percent									*lb acre 6 inches*	
UPPER:											
0-12 inches	39	44	17	22	11	4.4	0.8	0.179	6.5	65	828
12-25 inches	43	40	17	19	9	1.5	.6	.073	6.5	44	620
> 25 inches	43	38	19	21	9	.8	.5	.043	6.2	61	490
LOWER:											
0-12 inches	39	44	17	22	12	5.3	.6	.210	6.2	52	798
12-25 inches	37	47	16	19	9	2.7	.6	.118	6.2	51	752
> 25 inches	51	35	14	17	8	1.0	.5	.052	6.2	42	540

[1] Analyses were completed by Cooperative Soils Laboratory, Colorado State University.

RANGE MANAGEMENT PRACTICES

Proper Grazing

Present knowledge is generally adequate for determining an acceptable level of grazing on mountain grasslands. Proper use from the standpoint of forage and livestock production basically aims to maintain or increase the productivity of grasslands through wise management. Concurrently, the condition and management of mountain grasslands influence the use of interspersed aspen and shrub ranges.

Among the factors that influence actual utilization of a plant species are its abundance, composition of associated vegetation, habits of the animals, stage of plant growth, climatic conditions, and management practices (Cassady 1941). Grazing of approximately 40 percent of the annual growth of palatable grasses by the end of the grazing period is generally recognized as not being detrimental to mountain grassland ranges that are in satisfactory condition.

Although Idaho fescue is a primary forage species on many mountain grassland ranges in Colorado and Wyoming, cattle use a number of other grasses and forbs; the latter are often grazed early in the grazing season (see table 2). Aspen fleabane, aspen peavine, and agoseris were among the more important forbs on Black Mesa in western Colorado (Paulsen 1969).

Shrubs seldom contribute appreciably to the diet of cattle on mountain grassland ranges. However, aspen root suckers are often browsed by livestock and big game. On Black Mesa, elk sedge ranked highest of the herbaceous species on aspen ranges intermingled with mountain grasslands (table 4).

Table 4.--Production, cattle preference, and relative forage value for forage species on aspen ranges, Black Mesa Experimental Forest and Range, Colorado (from Paulsen 1969)

Species	Production	Utilization by number of days grazed				Forage value[1]
		18	36	56	78	
	[illegible]	[illegible]				
GRASSES AND GRASSLIKE:						
Elk sedge	205	2	5	8	9	1.00
Fringed brome	24	4	8	13	17	.22
Mountain brome	10	3	14		22	.11
Thurber fescue	24	3	12	18	7	.11
Slender wheatgrass	9	4	6	24	11	.06
Others	5					
FORBS:						
Meadowrue	44	1	6	15		.39
False sunflower	14	10	11	37		.28
Aspen peavine	59	2	3	7		.22
Fireweed	10	4	6	18		.11
Thistle	11	4	14	13		.06
Northern bedstraw	17	1	2	6		.06
Butterweed groundsel	21		1	5		.06
Others	279					

[1] Ranking based upon the product of final utilization and production divided by the product obtained for elk sedge. Species listed were present on at least 5 percent of the plots.

In the Big Horn Mountains of Wyoming, Idaho fescue furnished 75 percent of the cattle diet on grasslands underlain by soils of granitic origin (Pond and Smith 1971). On ranges underlain by sedimentary soils, a combination of Idaho fescue, big bluegrass, and wheatgrasses supplied 70 percent of the cattle diet; forbs made up only 10 percent. Silky lupine, though not the most palatable forb, provided most of the forb herbage consumed.

Sheep grazing Idaho fescue on the Big Horn Mountains preferred forbs over grasses (Pond and Smith 1971). Many of the more preferred species were not among the 10 most important plants in the animal diet, however (table 5). In western Colorado, important plants in the diet of sheep grazing on summer range were common dandelion, aspen fleabane, Porter ligusticum, purple meadowrue, and tall larkspur (Doran 1943). Less preferred species such as hairy goldaster, mountain thermopsis, and orange sneezeweed may be utilized 10 percent or less when more desirable species are present, but as much as 50 to 80 percent when desirable species are scarce (Cassady 1941). Some species are utilized to a greater extent when rare than when abundant; for example, silvery lupine, elephanthead pedicularis, and showy frasera. Certain species are preferred during short periods, while others are grazed throughout the grazing season; examples of the latter are common dandelion, western snowberry, and aspen peavine.

Table 5.--Rank of important forage plants in the diet and preference of sheep, Big Horn Mountains, Wyoming (May 1960)

Species	Basin sites		Ridge sites	
	Sheep diet	Preference	Sheep diet	Preference
Silky lupine	1	6	6	3
Asters and fleabanes	2	3	3	5
Wheatgrasses	3	4		
Dunhead sedge	4	5		
Avens	5	10		
Pale agoseris	6	2		
Common dandelion	7	1		
Flowery phlox	8	7		
Sandberg bluegrass	9	8	5	4
Blueleaf cinquefoil	10	9		
Needleleaf and Hepburn sedges			1	2
Timber danthonia			2	6
Silky crazyweed			4	1
Idaho fescue			7	7

Kinds of Animals

Mountain grasslands are generally suitable for grazing by many kinds of herbivores. Cattle prefer areas with gentle terrain and a predominance of palatable grasses. Those with a more rugged terrain and vegetation rich in forbs and browse are more suitable for sheep. Elk obtain much of their summer food supply from grasslands, while deer depend mainly on forage from associated brushland and timber types. However, small grassland openings and borders of large grasslands are important habitat for deer, elk, and other wildlife.

Factors that influence or determine the kind of livestock with which a range is stocked include: (1) availability and distribution of water; (2) kind, extent, and distribution of vegetation types; (3) composition of herbaceous and shrubby vegetation; (4) range condition and management goal; (5) feasibility of livestock control; (6) economic considerations; (7) history, policy, and allocations of range use; (8) conflict with other uses or interests; and (9) personal preferences and desires of ranchers or livestock associations. Except for operational complications and economic considerations, alternate or dual use of the range by sheep and cattle may offer a feasible, biologically sound, and effective means for controlling composition of rangeland vegetation.

Number of Animals

Proper stocking of mountain grasslands varies with: (1) kind, age, and size of animal; (2) range condition; (3) management objectives; (4) amount and quality of usable forage; (5) system of grazing; (6) season of grazing; (7) length of grazing period; (8) kind, extent, and distribution of associated vegetation types; and (9) uniformity of livestock distribution. As on other types, a key indicator of proper stocking is the intensity of forage use. The range manager must recognize variation in forage production attributable to weather, and avoid use that over the long term would result in range deterioration.

Under continuous, seasonlong use, the grazing capacity of mountain grassland range in good condition is about 1.5 acres per AUM (USDA-FS 1962). It may be somewhat higher under ideal conditions and much lower under less favorable conditions. About 2.5 acres per AUM may be a reasonable overall estimate for the type. Yearlings require two-thirds to three-fourths as much forage as fully grown cattle.

If the management objective is to achieve relatively light use and high individual weight gains, stocking should be relatively light. If closer use of the range is permissible and individual weight gains are less important, stocking can be heavier. More live weight gain per acre results from the latter, unless the range is stocked too heavily. Use of the more productive and palatable grasses, such as Idaho fescue, should not exceed 40 to 45 percent on properly stocked range grazed seasonlong (Beetle and others 1961). Whether mountain grasslands can be stocked more heavily for short or intermittent periods without causing damage to the range has not been determined.

To utilize palatable and nutritive forbs more fully, stocking may be somewhat heavier during the forepart of the grazing season than in the fall when many plants have dried and shriveled. Grass use tends to increase as forbs become less readily available (Paulsen 1969).

Season of Grazing

Guidelines for range readiness are generally similar though more conservative than those developed 50 years ago by Jardine and Anderson (1919). Guides for cattle ranges usually stipulate that important perennial grasses be headed out, and that the soil be sufficiently firm to avoid trampling damage by livestock. On sheep range, flowering of principal forbs may be the basic criterion. Dates of snow disappearance and other weather characteristics generally indicate when those stages may be attained (Costello and Price 1939).

Closing of the grazing season usually is dictated by weather and/or quantity and quality of remaining forage. The grazing season for sheep ordinarily is shorter than that for cattle because most sheep range is at higher elevations where plants develop later and much of the forage is damaged or destroyed by frost early in the fall.

From investigations of seasonal trends in carbohydrate reserves, McCarty and Price (1942) concluded that grazing of plants during their reproductive period is especially harmful. Because early grazing is limited by wetness of soil and scarcity of forage, and late grazing by reduced palatability of most plants, poor-quality forage, and adverse weather conditions, they decided that moderate use was the key to management of rangelands supporting mountain brome and slender wheatgrass. They suggested that grazing be intermittent, rotated, or slackened periodically to allow for seed production and range seeding.

The summer forage supply is both larger and more nutritious than that available early in spring or late in fall. Most grass and sedge herbage appears to be nutritionally deficient after late August. Chemical analyses of forage collected on Black Mesa at specific phenological stages are shown in table 6.

Through the first half of the grazing period on Black Mesa, three forbs that furnished appreciable amounts of forage were nutritionally superior to the grasses. Even after the forbs were dry and decumbent, they showed crude protein, phosphorus, and calcium levels above the minimum nutrient requirements prescribed for maintaining normal growth of 600-pound steers or heifers (Natl. Res. Counc. 1963). Analyses of forage species of the Big Horn Mountains, Wyoming, showed similar nutritional values and seasonal trends (Pond and Smith 1971).

Grazing Systems

The basic purpose of a grazing system is to insure that plant and soil resources continue to be productive. Selection and adoption of any system will depend upon the kind of vegetation, the physiography of the range, the kind of animals, and the objectives of the manager (Stoddart and others 1975). Regardless of the system used, one of the most difficult jobs

Table 6.--Percentage crude protein, phosphorus, and calcium of major forage species, 1962-63, Black Mesa Experimental Forest and Range, Colorado (from Paulsen 1969)

Nutrient and species	Phenological development			
	Leaves only	Flowering	Seed ripening and dispersal	Regrowth; dormancy
CRUDE PROTEIN:				
Idaho fescue		9.8	9.0	7.0
Thurber fescue		9.8	8.6	6.1
Letterman needlegrass		11.8	9.6	7.0
Slender wheatgrass		9.5	11.9	5.5
Bromegrass		11.4	11.4	7.1
Elk sedge				10.2
Aspen fleabane	18.1	14.8	12.0	11.0
Agoseris		15.1	11.6	11.2
Aspen peavine		21.7	21.5	17.8
PHOSPHORUS:				
Idaho fescue		.21	.15	.12
Thurber fescue		.19	.14	.12
Letterman needlegrass		.18	.14	.09
Slender wheatgrass		.20	.28	.11
Bromegrass		.24	.36	.13
Elk sedge				.18
Aspen fleabane	.40	.31	.21	.24
Agoseris		.38	.36	.34
Aspen peavine		.23	.22	.18
CALCIUM:				
Idaho fescue		.56	.62	.55
Thurber fescue		.36	.39	.31
Letterman needlegrass		.56	.52	.46
Slender wheatgrass		.44	.45	.47
Bromegrass		.58	.54	.57
Elk sedge				.58
Aspen fleabane	1.46	1.31	1.74	1.74
Agoseris		1.94	2.04	2.84
Aspen peavine		1.66	1.78	2.29

in range management is to obtain uniform utilization of the forage resource (Driscoll 1967). Common range management practices such as salting, supplying water, installing fences, and riding or herding complement each other in overcoming many grazing distribution problems.

Continuous grazing has been practiced on mountain grassland ranges for many years. Much too frequently it has been employed with too many livestock over too long a season. Undesirable successional changes in plant cover have resulted where animals grazed available forage from time of snowmelt until snow or cold weather forced them to lower elevations. Continuous grazing, however, does not mean simply closing the gate and letting livestock graze at will without attention to proven principles of range management. Continuous grazing can achieve any desired degree of use. It has often been judged successful on moderately stocked ranges where other management practices have been added to achieve desired goals. The system is best adapted to small range units in relatively good condition and on which livestock distribution is not a problem. Cattle need not adjust to abrupt changes in forage supply, and animal weight gains are commonly higher than under other systems. In comparison to other systems, continuous grazing requires the least investment for range improvements, minimum handling and movement of livestock and, generally, use of different classes of forage when they are most nutritious. However, disadvantages of continuous grazing cited by Driscoll (1967) are:

1. Animals tend to concentrate in the same places at the same time year after year.
2. Forage is often wasted because of poor distribution of livestock and its uneven utilization.
3. Even if the range unit is "properly" grazed, the better forage plants where livestock prefer to graze are overutilized and may be eliminated.

Early-day range managers of mountain grassland ranges perceived a need and advocated various grazing systems to improve range condition and obtain more uniform use of the range (Sampson 1913, Douglas 1915). With development and refinement of scientific principles of range management, numerous grazing systems have evolved that help meet the growth and reproductive requirements of the more important forage plants and maintain the range in relatively productive condition. Common terms which describe these systems include the following:

Deferred—a unit is not grazed until after seed maturity.
Rest—a unit is not grazed in a given year.
Rotation—units are grazed on a scheduled basis.

Various combinations of these terms are used to describe specific grazing plans, such as deferred-rotation or rest-rotation. Within this framework, plans may be developed that are contingent upon the number of herds, number of animals in each herd, number of range units or pastures, size of pastures, and dates or plant phenological stages when animals are to be moved (Heady 1975). They require that the range be divided into two or more units. The four most common systems have been described by Driscoll (1967): rotation or alternate grazing, deferred grazing, deferred-rotation grazing, and rest-rotation grazing. The number of units in these systems depends on the intensity of management and physical characteristics of the land. Fencing or careful herding, together with judiciously placed salt and water, usually are required to effectively control livestock distribution.

On many summer ranges, about one-third of the grazing season remains after seed maturity; on those ranges, at least three subunits are required. The unit or allotment should be subdivided so that all subunits have similar grazing capacities.

Cost of improvements needed to control livestock is the major deterrent to the adoption of specialized grazing systems. Fencing of mountainous rangeland is expensive, and economic considerations may preclude intensive management of many areas. Sheep ranges, of course, need not be fenced if sheep are controlled by herding. Subdividing the range into units suitable for refined grazing systems may be constrained by differences in elevation and plant development, natural barriers, unequal distribution of vegetation types, and other factors that prevent an individual unit from supplying its share of forage when needed (Stoddart and Smith 1955).

Development and distribution of water are usually costly, and may pose difficult problems in implementing deferred or rotation systems of grazing.

Although the expense of adopting specialized systems of grazing may not always be justified, experience has shown that range conditions usually improve under such management (Driscoll 1967). In a Wyoming study, either rotation or rest-rotation systems were found to benefit mountain ranges grazed by cattle (Johnson 1965). The most striking result was a reduction in utilization without a reduction in the number of animals grazing the areas. These systems are beneficial if the physiological needs of the vegetation are effectively met through proper planning and execution. However, on the Bighorn National Forest in Wyoming, a 7-year comparison of range conditions and cattle weight gains did not prove conclusively that rotation grazing in itself was better than seasonlong grazing (Pond and Smith 1971).

Decision as to the best system for grazing individual ranges must be based on local conditions and circumstances. Although various modifications of these grazing systems are now in operation on many mountainous rangelands, most have not been sufficiently evaluated.

A spinoff benefit that has been realized from adoption of some intensified system of grazing is the increased attention given to other facets of range management. For example, range seeding and noxious plant control are frequently included with fencing and water development in the overall management plan. Such range improvement practices may be integrated without fencing for grazing control into a management plan that incorporates rest in the grazing system.

Improving Forage Production

Seeding

Seeding of mountain grasslands may be needed and justified if satisfactory range condition cannot be restored within a reasonable time through grazing management or control of undesirable plants. Extreme scarcity of desirable plants, regardless of ground cover density, is one of the more obvious and reliable indicators of the need to reseed. Suitability of the site for seeding, need for additional forage, ability to protect and manage the seeded area, and costs and returns from seeding should be considered. An estimated 5 percent of the spruce-fir zone in Colorado is in need of seeding. Many of the better sites can be seeded on the basis of available guidelines (Stewart and others 1939, Doran 1951, Hull and others 1958, McGinnies and others 1963).

Although climate of the subalpine zone generally is conducive to successful seeding, failures may result from inadequate precipitation during the growing season or frost heaving during winter. Chances for successful seeding could be improved, however, with better understanding of the influence of weather on seedling development. Failures may occur if seedbed preparation is inadequate or seeded stands are improperly managed. Practical and generally effective methods for seeding unfavorable sites, such as those with shallow, rocky soils, or those inaccessible to equipment for preparing the seedbed, have not been developed.

Species adapted to mountain grasslands are numerous. However, adapted legumes are generally needed to increase nitrogen content of the soil. Also, palatable and nutritious seeded grasses sometimes would be useful in providing forage earlier in the season than do native species.

Management of seeded ranges must be predicated on basic principles of good range management. Published guidelines (Stewart and others 1939, Doran 1951, Hull and others 1958) point out practices that will prevent depletion of seedings: (1) protecting seeded areas from grazing until plants are well established; (2) grazing at the proper season and intensity, commonly in separate units; (3) fertilizing high producing stands; (4) occasional mowing at the end of the grazing period to clean up the coarse, ungrazed plants; and (5) providing for flexibility in stocking to accommodate variation in herbage yields. Insofar as is known, no controlled experiments have been conducted to determine and compare responses of seeded ranges in the subalpine zone to different systems of grazing.

Costs of seeding and related improvements needed for management of seeded areas vary widely. Conditions under which seeding of mountain grasslands is economically feasible have not been adequately determined. Return from the investment varies, of course, not only with fixed costs but with initial success of and subsequent production from the seeding.

Noxious Plant and Animal Control

Noxious or undesirable plants have been controlled mainly with chemical herbicides. Mechanical methods, except possibly for control of tall larkspur and big sagebrush, have generally been ineffective, impractical, or uneconomic. Biological methods have received little attention and, as far is known, are not available for or applicable to noxious plants on mountain grasslands.

Herbicides can effectively control many range plants, both desirable and undesirable. Numerous kinds have been developed, and the more common ones, especially 2,4-D and 2,4,5-T, have been widely used for many years. Basic principles of herbicide use are reasonably well known (Romancier 1965, Freed and Morris 1967), and guidelines for controlling several plant species on mountain grasslands are available (U.S. Range Seeding Equip. Comm. 1966). Use of herbicides has been directed mainly at controlling individual forb or shrub species considered to be undesirable. Such practice frequently has resulted in increased grass production and improved range condition where grasses were relatively abundant prior to treatment.

Some target plants survive herbicide applications because of differences in phenological development, genetic composition, a supply of viable seeds in the soil, or resistance to certain kinds or concentrations of herbicides (Roché 1971). Such plants may become more prominent following treatment and, if undesirable, may intensify the problem of plant control (McKell and Chilcote 1957).

Parry rabbitbrush and Fremont geranium, prevalent species on some mountain grasslands, are resistant to commonly used herbicides, and satisfactory methods for their control have not been developed. Tordon offers promise but is expensive (Paulsen and Miller 1968). Control of certain poisonous plants, such as the low larkspurs, also has been ineffective or impractical on mountain grasslands.

On rangelands sprayed with herbicide, livestock are usually removed for 1 to 3 years to obtain the greatest possible benefit from spraying. Smith's (1969a) results indicate that satisfactory improvement may be obtained under moderate grazing without deferment. Future use of herbicides for increasing the forage supply may hinge on their overall effects on the environment.

Where pocket gophers are abundant enough to consume or destroy a sizable part of the mountain grassland forage crop, they have been effectively controlled by killing with herbicide most of the forbs on which they rely for food (Hansen and Ward 1966). Because of restricted use of the known effective pesticides, a practical method for controlling gophers over extensive areas is not available.

Rodents other than pocket gophers, particularly montane voles and deer mice, are relatively common on mountain grasslands and when abundant they too may appreciably reduce the forage supply. Voles compete directly with livestock for forage, and deer mice influence the amount and availability of plant seed. In general, deer mice tend to be more abundant on rangeland with sparse cover, and voles on ranges with relatively dense cover (Tester and Marshall 1961). Suitability of the habitat for these rodents evidently can be influenced appreciably through intensity of grazing by livestock.

Insects, such as grasshoppers, occasionally destroy much rangeland forage. Their control also was severely hampered when certain insecticides were restricted or banned.

Dual use of summer range by livestock and big game may occasionally result in overuse and decline in forage production. Big game often move on to mountain grassland ranges as soon as the areas are free of snow. Where animals are concentrated, damage to the soil and forage resource may result. To achieve proper and balanced use under such conditions, adjustments in animal numbers and reallocation of rangeland to accommodate the needs of both may be necessary.

Fertilizing the Range

Grass yields, crude protein content, and palatability of mountain grassland vegetation may be increased under certain conditions by fertilizing the range with nitrogen (Smith and Lang 1962). Over a 5-year period in the Big Horn Mountains, Wyoming, significant increases in grass forage were obtained on a fine gravelly loam soil. With optimum application rate (50 pounds of available N per acre) the additional yield was estimated at 150 pounds of ovendry forage per acre. Maximum grass response was obtained when fertilization was combined with control of broad-leaved plants. However, the increase in each case did not approach what was considered economic feasibility. Under other experiments, little if any vegetation improvement was obtained from the application of nitrogen, phosphorus, potassium, sulfur, and several minor elements (Hull 1963).

Possibilities for changing composition of grassland vegetation through use of different kinds and amounts of fertilizer are evident from tests on mountain meadows (Cooper and Sawyer 1955). Nitrogen generally favors growth of grasses, while phosphorus and potassium encourage growth of legumes. On experimental plots on Black Mesa (Paulsen 1970b), applications of 350 pounds per acre of nitrogen from ammonium sulfate and 300 pounds per acre of phosphorus in superphosphate for 3 successive years significantly reduced the cover of Thurber fescue by the third year. The effect was also apparent on aspen fleabane and cinquefoil, two prominent forbs on the plots. Although Fremont geranium was the most abundant forb, fertilizer treatment had no effect on this species' cover.

As pointed out by Retzer (1954), plants will respond to fertilizer when the fertility status of a soil is low or unbalanced, but they will not respond when the fertility status is high and well balanced. Tests usually are needed to determine the status of soil nutrients. Ample rainfall and soil moisture are required for the vegetation to effectively use the fertilizer. On relatively infertile soils, best results may be achieved by fertilizing in conjunction with the control of noxious plants.

Water Spreading

Water spreading is seldom practiced on mountain grasslands. Its potential for appreciably increasing forage production is small, mainly because conditions rarely are suitable for adequate control of water on mountainous rangeland. On relatively flat terrain, water spreading may increase both quantity and quality of forage available as well as provide an effective means for controlling big sagebrush.

Contour trenching with other improvement practices such as seeding and grazing control have been successful on high range watersheds in the West. On moderately steep slopes, specialized equipment has been developed that can remove soil from a trench and move it downslope into a ridge while operating at a reasonably rapid speed (U.S. Range Seeding Equip. Comm. 1965).

Controlled Burning

Little is known about how fire influences productivity or floristic composition of mountain grasslands. Findings from various sources, as summarized by Wright (1971), indicate that fire will stimulate forage production in stagnated grassland communities. He concluded that "Huge buildups of litter lower soil temperatures which in turn reduce bacterial activity, tie up nutrients, and slow the general nitrogen cycling process, particularly during cool, wet years. In dry years, litter is important for insulation, protection from flash floods, and in general plants grow better if they are not burned."

Dead organic matter in relatively dense, lightly grazed stands of Thurber fescue may weigh more than 5 tons per acre (Turner and Dortignac 1954). Under such conditions burning may increase the quantity or improve the quality of forage. Where ground cover is sparse, or the range closely grazed, burning may be detrimental or infeasible. Under some conditions, controlled burning may influence not only the forage supply for livestock, but the kinds and abundance of wildlife (Miller 1963). Montane voles, for example, possibly could be reduced or controlled through prescribed burning since they tend to become more abundant with increased litter. Deer mice have become more abundant following fire (Wright 1971).

Prescribed burning also offers a potential means for controlling grassland insects and diseases. Implications of indirect effects of fire on wildlife and forage production are obvious and far reaching, but there is little in the literature that is specific for Thurber fescue or Wyoming bunchgrass ranges.

On grasslands with sagebrush overstory, fire may kill shrubs and release understory grasses. However, rabbitbrush is not readily killed by fire and, where present, it may become more abundant. Idaho fescue evidently is more readily damaged or destroyed by fire than are associated plants of bluebunch wheatgrass (Conrad and Poulton 1966). These findings indicate that fire may play an important role in determining composition of grassland vegetation. By deterring encroachment of trees into grassland openings, fire tends to maintain the grassland openings.

Increasing Range Usability

Practices to improve cattle distribution and thus increase usability of mountain rangelands, as summarized by Skovlin (1965), are generally applicable to mountain grasslands of the central Rockies. Briefly, they are as follows:

1. Develop water supplies on ungrazed areas to reduce grazing pressure near existing water.
2. Fence to limit use to the best season and to control grazing between range types.
3. Add salt grounds to lightly grazed areas at locations that will encourage greater use.
4. Redistribute cattle through range riding, moving them from heavily grazed range to lightly grazed or ungrazed range.
5. Construct trails or driftways to improve access to isolated tracts.
6. Manage native forage through manipulation of the plant cover.

Relatively uniform use of sheep range can be achieved by conscientious herding. Maximum usability of cattle range, however, can be attained by applying several complementary practices. For each range or range unit, practices must be tailored to fit local conditions. A basic question is whether such practices, or which practices, are actually needed or economically justified. The basic tools with which to obtain uniform use of the range are available.

Cost data for range improvement practices on mountain grassland ranges were summarized from Duran and Kaiser (1972) (table 7). Since their values were averages, other data may vary from those presented. Costs of range improvements commonly are shared by the rancher and Government when livestock are grazed on Federally owned land and the practices are considered mutually beneficial.

Table 7.--Costs and life expectancy for range improvement practices on mountain grassland ranges (from Duran and Kaiser 1972)

Practice and costs	High-production sites	Low-production sites	Life expectancy
			Years
PER ACRE:			
Seeding	$ 5.50	$ 8.50	30
Noxious plant control	5.00	5.50	15
Rodent control	3.50	3.50	30
Insect and disease control	1.50	1.50	20
Fertilization	15.00	15.00	2
Water spreading[1]	7.00	8.00	30
Controlled burning	3.00	3.00	5
PER MILE:			
Fencing	1,500.00	2,200.00	25
EACH:			
Water developments	350.00	600.00	30

[1] Authors include practices such as sprinklers and ditches to provide water to areas deficient in moisture.

Managing the Livestock

Many animals are grass-fat when removed from mountain grassland range. Forage nutrient changes are reflected in animal weight gains however, which almost invariably decline with advance of the season (Pond and Smith 1971). Yearling cattle on Black Mesa showed an average gain of 1.5 pounds per head per day from approximately September 1 until October 1. The gain from mid-July until September 1 averaged 2.4 pounds per head per day, or about 62 percent more than late in the season. In the Big Horn Mountains of northern Wyoming, the average daily gain per steer was 1.89, 2.22, and 2.41 pounds for heavy, moderate, and light forage use, respectively (Beetle and others 1961). Livestock may occasionally lose weight during periods of inclement weather or inadequate forage supply. Though economically important in the production of grass-fat animals for market, such loss may not be detrimental to maintenance of the breeding herd.

By fall, crude protein and phosphorus content of the more common grasses may approach minimum levels recommended for maintenance of cows and calves, especially when rainfall is deficient (Paulsen 1969, Pond and Smith 1971). Calcium content of forage evidently remains sufficiently high throughout the summer. Although mineralized salt commonly is provided, the need for it in addition to common salt has not been established. Nutrient deficiencies on summer ranges usually are not serious, and supplements seldom are fed there. Open-grown forage tends to have a higher carbohydrate content than that grown in shade (Watkins 1940). Fragmentary records indicate that weight gains of cattle on grassland are higher than on cattle confined to aspen groves.

Death losses from low larkspur, a serious problem on some mountain grassland ranges, may be avoided by withholding cattle from the range until most of the plants have dried up. Losses from tall larkspur may be reduced by fencing out highly infested areas or control of individual plants. Relatively few cattle are lost to predators.

Traditionally, a good herder has been considered the key to good management of sheep on mountain grassland/aspen range. Limited comparisons indicate, however, that sheep may not need to be herded on fenced mountain rangeland. Such practice resulted in satisfactory use of the forage resource in Wyoming (Jones and Paddock 1966). Former losses of sheep on range infested with orange sneezeweed have been greatly reduced by improved management practices such as open herding where there is an ample supply of palatable forage, avoidance of sneezeweed areas, and general improvement of range condition. Losses of sheep to predators are often high, and possibly will increase with increasing restrictions on predator control. Relationships between predators and sheep losses are being further investigated.

LIVESTOCK GRAZING AND OTHER USES

Water and Timber Production

Good range management usually is considered good watershed management, particularly in regard to maintaining soil stability; properly managed grazing animals seldom are detrimental to watersheds in satisfactory condition. However, Gary (1975) concluded that while good range management and revegetation will improve watershed conditions, such measures do not assure that intense runoff will not occur during severe storms.

Most mountain grasslands in the central Rockies support a denser cover and are less subject to erosion than those at lower elevation. From plot tests on numerous grassland sites in western Colorado, Turner and Dortignac (1954) found that infiltration rates were relatively high, and erosion rates were low, under most conditions. Infiltration rates were lowest on sites dominated by Kentucky bluegrass. Erosion rates were high where ground cover was sparse and much bare soil was exposed.

On Black Mesa watersheds, Frank and others (1975) found no significant change in runoff or sediment production attributable to various intensities of cattle grazing. According to their records, 99 percent of total yearly runoff and 89 percent of suspended sediment were produced during spring snowmelt. Sediment yields were small, and apparently came from a few local areas such as stream channels and other sites with little protective cover. Soil recently deposited on the ground surface by pocket gophers probably contributed to sediment movement.

Leaf (1975) concluded that moderate intensities of cattle grazing do not affect water runoff on watersheds with extensive grassland parks.

Water use by mountain grassland and adjacent spruce-fir and aspen types was compared on Black Mesa (Brown and Thompson 1965). Soils sampled gravimetrically to an 8-foot depth showed average total water use in inches per day for three summer growing seasons of 0.165 for aspen, 0.132 for spruce-fir, and 0.079 for grassland.

Little is known about water yields from mountain grasslands, although estimates approximating those characterizing adjacent forest types may be appropriate (Ffolliott and Thorud 1974). Livestock trampling tends to compact the soil and increase surface runoff. The extent to which grazing affects the yields of usable water from high-elevation rangelands by reducing transpiration or increasing evaporation is not known.

Contamination of domestic water supplies by livestock has received little attention. In general, concentrations of all chemical water-quality components in subalpine streams are low (Leaf 1975). Bacterial counts vary widely, but a strong positive bacteria-to-flow relationship can be expected. High concentrations associated with grazing and recreation appear to result from the "flushing effect" of runoff from snowmelt and summer storms. In some areas, siltation resulting from range use by livestock has made streams unsuitable for fish. Browsing of streamside willows and other shrubs also has generally degraded fish habitat by increasing exposure to sunlight and raising water temperature.

Browsing and trampling occasionally damage or destroy coniferous tree seedlings and saplings adjacent to mountain grassland openings within the forest. If such damage is detrimental, fencing of forest plantations or removal of livestock may be required to prevent damage to young trees. However, on properly stocked rangeland, conflicts involving damage to natural regeneration of timber and livestock production seldom are serious.

Aspen stands intermingled with mountain grasslands, however, are more apt to suffer animal damage. Browsing of aspen root suckers by livestock and big game may be sufficiently severe to curtail its sprouting capability. Stripping of aspen bark by elk and rodents exposes the trees to disease and reduces esthetic value of the stands.

Improper grazing by cattle may result in increased abundance of forbs that serve as alternate hosts for timber-damaging fungi. Chickweed is an alternate host for *Melampsorella caryophyllacearum,* the causal agent of fir broom rust (Peterson 1964). Comandra is the alternate host for *Cronartium comandrae,* which causes widespread mortality of lodgepole pine (Tackle 1959). Laycock and Krebill (1967) reported that, although comandra is not readily eaten by cattle, it could increase on overgrazed range when selective grazing pressure causes the more palatable species to decrease; the evidence, however, is conflicting.

Wildlife and Recreation

Mountain grasslands provide much forage for game and nongame animals in the central Rockies. Although the habitat of most animals in the subalpine zone is an admixture of vegetation types, grasslands are an important part of the complex.

Estimated numbers of big game within and harvested from National Forests in Colorado and Wyoming in 1972 were as follows:

	Number present	**Number harvested**
Pronghorn	14,000	3,000
Whitetail deer	2,000	184
Mule deer	296,000	36,000
Elk	102,000	18,000
Moose	820	85
Mountain goat	450	5
Bighorn sheep	5,100	95
Black bear	6,500	380
Grizzly bear	110	1
Turkey	6,000	256

During part of the year most of these species make some use of mountain grasslands in conjunction with adjacent forest.

Openings created by logging of the coniferous forest often furnish temporary forage for livestock and wildlife until tree reproduction again occupies the site. Forage species are often the same as those of intermingled mountain grasslands. Total forage production usually begins to decline after 10 years, and new openings should be cut about every 20 years to maintain this source of forage.

In comparisons of the use made by cattle, elk, and deer of natural and created openings (logged areas) in spruce-fir forests in Arizona, Reynolds (1966) found that cattle preferred the natural openings whereas deer and elk preferred the created openings. In Wyoming, however, Ward and others (1973) reported similar grazing patterns and area preferences for elk and cattle, which were often observed within 200 yards of each other.

In Arizona, elk and deer preferred created openings; however, openings larger than 20 acres were little used by game except near the forest borders. Wallmo (1969) reported that alternating cut and uncut strips 3 chains wide attracted the most deer use. Size of the natural openings was not a factor in influencing cattle grazing. Increased amounts of variety of high-quality forage are the obvious attractions in openings.

Although the above studies indicate the impact of timber harvesting practices on wildlife, information on the size, shape, and arrangement of cutover units or the periodicity of cutting required to maintain desired habitat conditions needs to be refined. These data are needed to provide the numerical input for mathematical models of timber–wildlife interactions. Additionally, not enough information is available on nongame animals or their habitat requirements to adequately assess the impact of timber harvesting practices.

Visitor-days' use of National Forests and Grasslands in the Rocky Mountain Region by hunters and fishermen during 1971 were estimated to be 1,422,000 days spent fishing, 876,000 days hunting for big game, and 57,000 days hunting for small game animals. Production, use, and enjoyment of wildlife doubtless are influenced appreciably by the manner and degree to which mountain grasslands are grazed by livestock.

To some people, the presence of livestock on the range adds to scenic interest and attractiveness. To others, livestock are a nuisance, especially around campgrounds. Tourists occasionally disturb livestock, and visitor activities may reduce the amount of rangeland suitable for grazing. In general, conflicts between grazing and recreation do not appear to be serious or widespread, but problems may develop locally as recreation demands increase.

The preceding discussion centered on how livestock grazing affects associated resource values of the subalpine region. Because of the overriding influence of the forest overstory, the impact of various timber cutting practices on these products and values should also be considered.

Various systems of cutting the overstory have been evaluated on a 0-5 scale (fig. 6). The ratings of wildlife habitat, livestock forage, and water yield are relatively high for the clearcutting and group-selection harvest systems, somewhat lower for the shelterwood system, followed by the selection system, with the effect of no cutting rated lowest. In contrast, the rating of the esthetic appeal of the forest stand improved as more of the stand was left undisturbed. Refinement and quantification of the ratings are needed to improve understanding of the interactions between the products and values.

EMERGING DEMANDS FOR MOUNTAIN GRASSLAND RESOURCES

Mountain grasslands of the central Rockies are an integral part of the subalpine zone, which is a major source of water for millions of people as far away as California and Mexico. The area's outstanding beauty and its developing yearlong recreational opportunities are attracting increasing numbers of people nationwide, and forcing change upon the more traditional uses of the zone. Nevertheless, mountain grassland and associated ranges are locally important. Ranchers, dependent on these ranges for summer grazing, contribute much to the economy of small communities. Some foresee continued or increased demand for mountain rangelands to maintain beef breeding herds as part of an integrated and more efficient livestock industry (Hodgson and Hodgson 1971). Others believe that future production of range livestock will shift to highly productive range and pasture lands in the South and East (Blaisdell and others 1970).

In view of (1) the increasing demand for beef, (2) the need to limit the amount of flammable vegetation on grazable areas, (3) the likelihood that grazing is not detrimental to maintenance of high yields of usable water, and (4) the importance of ranching to the welfare of local communities, continued grazing of mountain grasslands appears feasible and desirable. There is no doubt, however, that demands for mountain grasslands for various purposes will increase, and that local adjustments will be needed to accommodate those uses and demands. To do so adequately will require more intensive application of known range management principles and practices, as well as the development of new knowledge and tools that will enhance the land managers' capabilities.

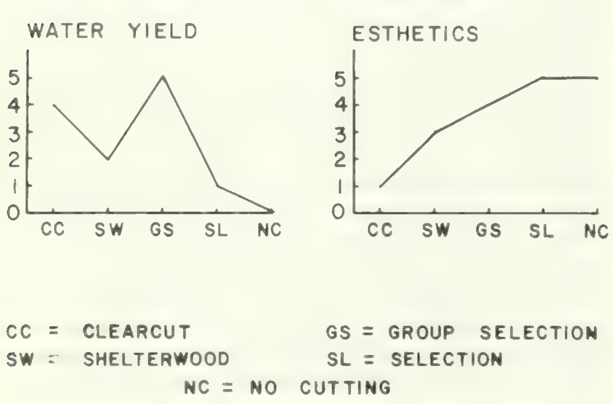

Figure 6.—Relationship of four resources in the subalpine forest zone to different cutting systems on a 0 to 5 rating scale.

LAND MANAGEMENT PROBLEMS AND RESEARCH NEEDS

Knowledge is generally adequate for extensive management of mountain grasslands in the central Rockies. Unfortunately, not all the knowledge necessary for efficient management is readily accessible to the manager. Furthermore, since grazing management is being complicated by increasing demands for rangeland uses, the contemporary range manager must increasingly direct his efforts to multiple use management in its broadest sense. Bases for this management must be developed through research to determine how various land management practices influence the productivity and quality of all resources, the complex processes and interactions involved, and tradeoffs among various uses and products. The manager also will have to take advantage of modern and developing technologies such as remote sensing, other refined measurement techniques, computer-assisted data handling, and evaluations of complex socioeconomic factors.

Nonetheless, the need persists for additional sound resource data that can provide a better basis for achieving the goals of more intensive range management. Urgent needs relative to management of mountain grasslands are improved guidelines for estimating site capability, and increased knowledge of the autecology of important plant components and their responses to grazing. Development of criteria for classifying mountain grasslands according to their potential, as has been done for other range types (Renner and Allred 1962), would be an important step in that direction. Additional perplexing aspects of range management that confront the manager and for which specific research information is inadequate already have been mentioned. The most significant ones are:

- Identification, description, and correlation of mountain grassland soils.

- Causes of annual variations in grass:forb herbage production.

- Factors controlling production of viable seeds of major forage species.

- Influence of fire, erosion, phytotoxins, and soil nutrients on mountain grassland succession.

- The role of biological agents and physical factors of the environment in fostering or limiting changes in mountain grassland communities.

- Long-term effects of grazing on soil productivity, the disposition of ungrazed plant residues, and amounts of residues needed to maintain soil organic matter.

- Specific effects of heavy stocking for short periods on vegetation and soils.

- Methods for seeding unfavorable sites, and improved understanding of the needs for seedling growth and establishment.

- Effects on the ecosystem of manipulating individual biological components.

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COMMON AND SCIENTIFIC NAMES OF PLANTS AND ANIMALS MENTIONED OR FOUND IN THE MOUNTAIN GRASSLANDS

Grasses and Grasslike

B egrass, big	*Poa ampla* Merr.
B egrass, Canby	*Poa canbyi* (Scribn.) Piper
B egrass, Cusick	*Poa cusickii* Vasey
B egrass, inland	*Poa interior* Rydb.
B egrass, Kentucky	*Poa pratensis* L.
B egrass, mutton	*Poa fendleriana* (Steud.) Vasey
B egrass, Sandberg	*Poa secunda* Presl.
B me, fringed	*Bromus ciliatus* L.
B me, mountain	*Bromus marginatus* Nees. *Bromus carinatus* Hook. & Arn.
B me, pumpelly	*Bromus pumpellianus* Scribn.
B megrass	*Bromus anomalus* Rupr.
D nthonia, timber	*Danthonia intermedia* Vasey
F cue, Idaho	*Festuca idahoensis* Elmer
F cue, Thurber	*Festuca thurberi* Vasey
H rgrass, tufted	*Deschampsia caespitosa* (L.) Beauv.
J egrass, prairie	*Koeleria cristata* (L.) Pers.
N dlegrass	*Stipa* spp.
N dlegrass, letterman	*Stipa lettermani* Vasey
N dlegrass, subalpine	*Stipa columbiana* Macoun
S ge	*Carex* spp.
S ge, dunhead	*Carex phaeocephala* Piper
S ge, elk	*Carex geyeri* Boott.
S ge, Hepburn	*Carex hepburnii* Boott.
S ge, needleleaf	*Carex obtusata* Lilj.
S kefescue	*Hesperochloa kingii* (S. Wats.) Rydb.
T othy	*Phleum pratense* L.
T othy, alpine	*Phleum alpinum* L.
W eatgrass	*Agropyron* spp.
W eatgrass, bluebunch	*Agropyron spicatum* (Pursh) Scribn. & Smith
W eatgrass, slender	*Agropyron trachycaulum* (Link) Malte
W eatgrass, thickspike	*Agropyron dasystachyum* (Hook.) Scribn.
W eatgrass, western	*Agropyron smithii* Rydb.

Forbs

A seris	*Agoseris* spp.
A seris, pale	*Agoseris glauca* (Pursh) D. Dietr.
A r	*Aster* spp.
A ns	*Geum ciliatum* Pursh
B uty, spring	*Claytonia lanceolata* Pursh
B straw, northern	*Galium boreale* L.
B bell, greenleaf	*Mertensia viridus* A. Nels.
C stium, starry	*Cerastium arvense* L.
C kweed	*Stellaria media* (L.) Cyrill.
C quefoil	*Potentilla* spp.
C quefoil, blueleaf	*Potentilla glaucophylla* Lehm.
C quefoil, Nuttall	*Potentilla nuttallii* Lehm.
C andra	*Comandra* spp.
C zyweed, silky	*Oxytropis sericea* Nutt.
D delion, common	*Taraxacum officinale* Wiggars
Fi weed	*Epilobium angustifolium* L.
Fl bane	*Erigeron* spp.
Fl bane, aspen	*Erigeron speciosus* (Lindl.) DC
Fr era, showy	*Frasera speciosa* Griseb.
G anium, Fremont	*Geranium fremontii* Torr. ex Gray
G anium sticky	*Geranium viscosissimum* F. and M.
G daster, hairy	*Chrysopsis villosa* (Pursh) Nutt. ex DC.
G denrod	*Solidago* spp.
G undsel, butterweed	*Senecio serra* Hook.
Ja ine, rock	*Androsace septentrionalis* L.
La spur	*Delphinium* spp.
La spur, duncecap	*Delphinium occidentale* (Wats.) Wats.
La spur, low	*Delphinium nelsonii* Greene
La spur, tall	*Delphinium barbeyi* (Huth.) Huth.
Li sticum, Porter	*Ligusticum porteri* Coult. & Rose
Li fawn	*Erythronium grandiflorum* Pursh
Lupine, silky	*Lupinus sericeus* Pursh
Lupine, silvery	*Lupinus argenteus* Pursh
Meadowrue, purple	*Thalictrum dasycarpum* Fisch. & Lall. ex. Fisch., May & Lall.
Mulesear	*Wyethia* spp.
Peavine, aspen	*Lathyrus leucanthus* Rydb.
Pedicularis, elephanthead	*Pedicularis groenlandica* Retz.
Phlox, flowery	*Phlox multiflora* A. Nels.
Sneezeweed, orange	*Helenium hoopesii* A. Gray
Sunflower, false	*Helianthella quinquenervis* (Hook.) A. Gray
Thermopsis, mountain	*Thermopsis montana* Nutt. ex. T. & G.
Thistle	*Cirsium centaureae* (Rydb.) K. Schum.
Trumpet, Gabriel's	*Gilia aggregata* (Pursh) Spreng.
Valerian, sharpleaf	*Valeriana acutiloba* (Rydb.) F. G. Meyer
Yarrow, western	*Achillea lanulosa* Nutt.

Trees and Shrubs

Aspen, quaking	*Populus tremuloides* Michx.
Fir, subalpine	*Abies lasiocarpa* (Hook.) Nutt.
Oak, Gambel	*Quercus gambellii* Nutt.
Pine, lodgepole	*Pinus contorta* Dougl.
Pine, ponderosa	*Pinus ponderosa* Laws.
Rabbitbrush	*Chrysothamnus* spp.
Rabbitbrush, Parry	*Chrysothamnus parryi* (A. Gray) Greene
Sagebrush	*Artemisia* spp.
Sagebrush, big	*Artemisia tridentata* Nutt.
Sagebrush, silver	*Artemisia cana* Pursh
Snowberry, western	*Symphoricarpos occidentalis* Hook.
Spruce, Engelmann	*Picea engelmannii* Parry
Willow	*Salix* spp.

Mammals

Badger	*Taxidea taxus* (Schreber)
Bat, hoary	*Lasiurus cinereus* (Palisot de Beauvois)
Bat, little brown	*Myotis lucifugus* (Le Conte)
Bat, silver-haired	*Lasionycteris noctivagans* (Le Conte)
Bear, black	*Ursus americanus* Pallas
Bear, grizzly	*Ursus arctos* Linnaeus
Beaver	*Castor canadensis* Kuhl
Bobcat	*Lynx rufus* (Schreber)
Chipmunk, least	*Eutamias minimus* (Bachman)
Cottontail, mountain	*Sylvilagus nuttallii* (Bachman)
Coyote	*Canis latrans* Say
Deer, mule	*Odocoileus hemionus* (Rafinesque)
Deer, whitetail	*Odocoileus virginianus* (Zimmerman)
Elk	*Cervus elaphus* Eryteben
Fox, red	*Vulpes vulpes* (Linnaeus)
Goat, mountain	*Oreamnus americanus* (De Blainville)
Gopher, northern pocket	*Thomomys talpoides* (Richardson)
Jackrabbit, white-tailed	*Lepus townsendii* Bachman
Lion, mountain	*Felis concolor* Linnaeus
Marmot, yellow-bellied	*Marmota flaviventris* (Audubon and Bachman)
Marten	*Martes americana* (Turton)
Moose	*Alces alces* (Linnaeus)
Mouse, deer	*Peromyscus maniculatus* (Wagner)
Mouse, western jumping	*Zapus princeps* Allens
Pika	*Ochotona princeps* (Richardson)
Porcupine	*Erethizon dorsatum* (Linnaeus)
Pronghorn (antelope)	*Antilocapra americana* (Ord)
Sheep, bighorn	*Ovis canadensis* Shaw
Shrew, masked	*Sorex cinereus* Kerr
Shrew, vagrant	*Sorex vagrans* Baird
Skunk, striped	*Mephitis mephitis* (Schreber)
Squirrel, golden-mantled ground	*Spermophilus lateralis* (Say)
Vole, montane	*Microtus montanus* (Peale)
Weasel, long-tailed	*Mustela frenata* Lichtenstein
Woodrat, bushy-tailed	*Neotoma cinerea* (Ord)

Birds

Chickadee, mountain	*Parus gambeli* Ridgeway
Dipper	*Cinclus mexicanus* Swainson
Eagle, golden	*Aquila chrysaetos* (Linnaeus)
Finch, Cassin's	*Carpodacus cassinii* Baird
Flicker, common	*Colaptes auratus* (Linnaeus)
Flycatcher, Hammond's	*Empidonax hammondii* (Xantus)
Flycatcher, olive-sided	*Nuttallornis borealis* (Swainson)
Grosbeak, pine	*Pinicola enucleator* (Linnaeus)
Grouse, blue	*Dendragapus obscurus* (Say)
Hawk, red-tailed	*Buteo jamaicensis* (Gmelin)
Hummingbird, broad-tailed	*Selasphorus platycercus* (Swainson)
Jay, gray	*Perisoreus canadensis* (Linnaeus)
Jay, Steller's	*Cyanocitta stelleri* (Gmelin)
Junco, gray-headed	*Junco caniceps* (Woodhouse)
Kinglet, golden-crowned	*Regulus satrapa* Lichtenstein
Kinglet, ruby-crowned	*Regulus calendula* (Linnaeus)
Nutcracker, Clark's	*Nucifraga columbiana* (Wilson)
Nuthatch, red-breasted	*Sitta canadensis* Linnaeus
Owl, great horned	*Bubo virginianus* (Gmelin)
Pewee, western wood	*Contopus sordidulus* Sclater
Raven, common	*Corvus corax* Linnaeus
Robin, American	*Turdus migratorius* Linnaeus
Sapsucker, yellow-bellied	*Sphyrapicus varius* (Linnaeus)
Sapsucker, Williamson's	*Sphyrapicus thyroideus* (Cassin)
Siskin, pine	*Spinus pinus* (Wilson)
Sparrow, Lincoln's	*Melospiza lincolnii* (Audubon)
Sparrow, white-crowned	*Zonotrichia leucophrys* (Forster)
Swallow, violet-green	*Tachycineta thalassina* (Swainson)
Thrush, hermit	*Catharus guttatus* (Pallas)
Turkey	*Meleagris gallopavo* (Linnaeus)
Warbler, yellow-rumped	*Dendroica coronata* (Linnaeus)
Woodpecker, northern three-toed	*Picoides tridactylus* (Linnaeus)
Wren, house	*Troglodytes aldon* Vieillot

Reptiles and Amphibians

Snakes, garter	*Thamnophis* spp. Fitzinger
Salamander, tiger	*Ambystoma tigrinum* (Green)
Toad, western	*Bufo boreas* Baird and Girard
Frog, leopard	*Rana pipiens* Schreber

Turner, George T., and Harold A. Paulsen, Jr.
1976. Management of mountain grasslands in the central Rockies: The status of our knowledge. USDA For. Serv. Res. Pap. RM-161, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Mountain grasslands provide important summer grazing for livestock and big game. Knowledge is generally adequate for proper grazing management of these grasslands, but management and improvement costs tend to be relatively high because of their remoteness. Suggested improvements to increase range usability, improve forage production, and control livestock must be coordinated with water and timber production, and wildlife and recreation needs.

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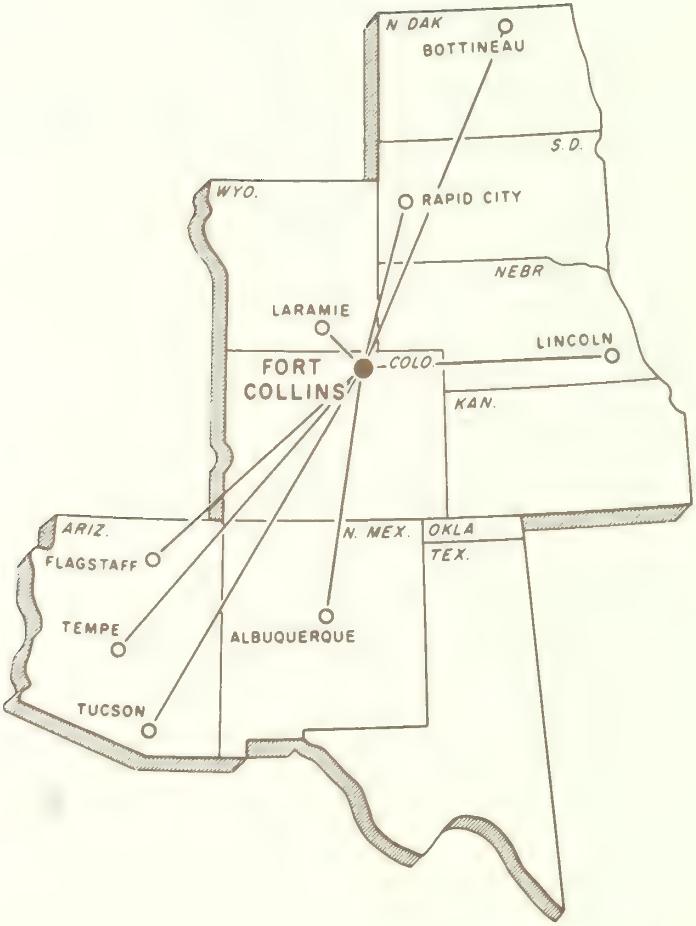
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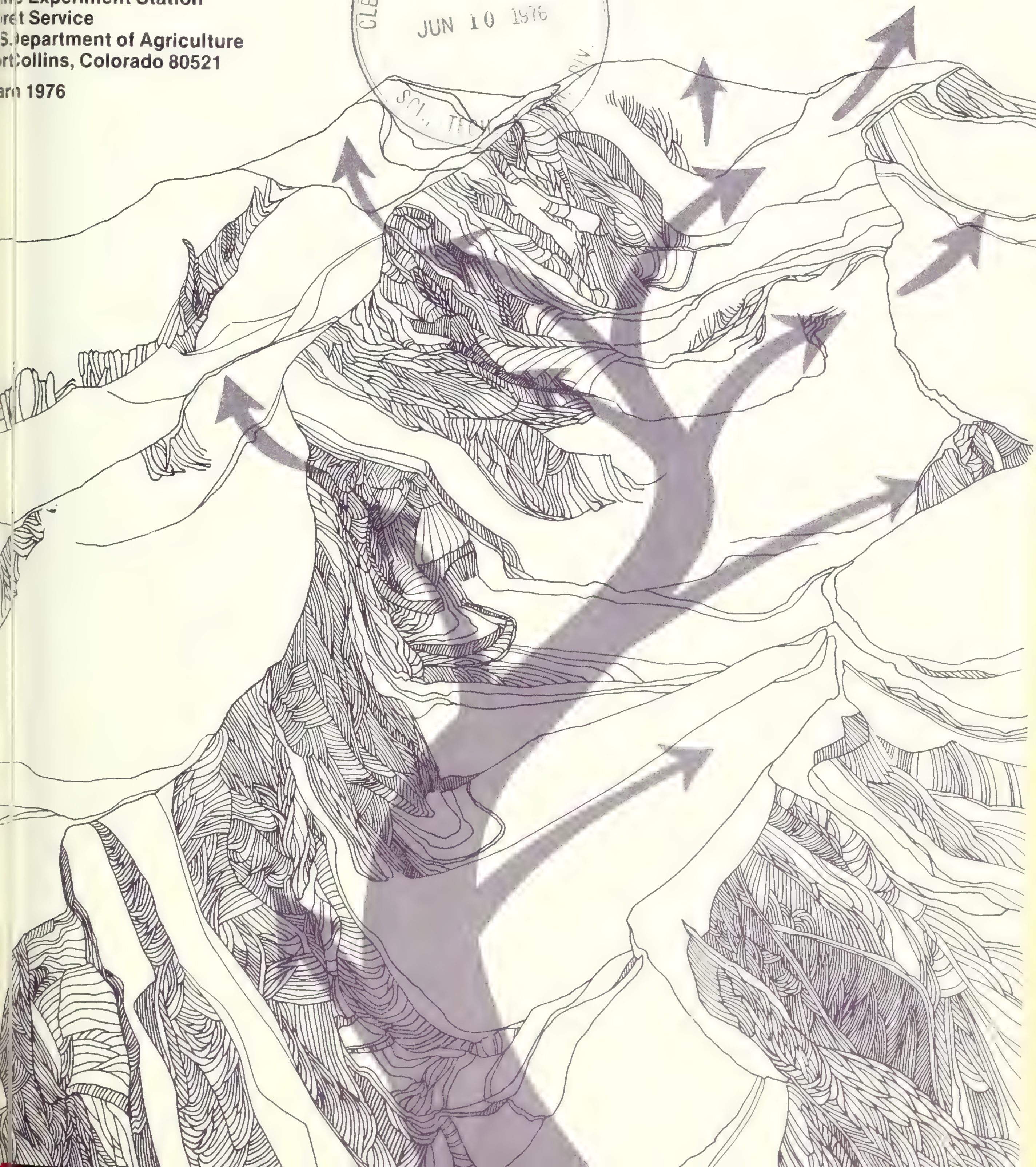

Abstract

Fosberg, Michael A., William E. Marlatt, and Lawrence Krupnak. 1976. Estimating airflow patterns over complex terrain. USDA For. Serv. Res. Pap. RM-162, 16 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

A simple one-layer model of atmospheric boundary layer flow was developed for use in complex terrain. The model was derived through simplification of the fundamental Navier-Stokes flow equations. This simplification was gained by neglecting advection terms in the equations of motion and by assuming an impulse solution.

Although the equations do not describe all flow characteristics, the resultant solution describes a diagnostic model of the vector flow field. It requires much less data than traditional approaches, and therefore can be used as an estimator of wind patterns in areas where dense observational networks are not economically feasible.

The intended primary uses for this model are in providing wind fields for fire behavior prediction and in evaluation of pollution transport patterns.

Keywords: Wind, boundary layer, air pollution, fire weather.

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Estimating Airflow Patterns Over Complex Terrain

Michael A. Fosberg,[1] William E. Marlatt,[2] and Lawrence Krupnak[3]

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Contents

Page
Introduction 1
Structure of the Model 2
  Throughflow Representation 2
  Thermal and Frictional Influences 3
  Calculation of Local Winds 5
  Flow Near the Ground Surface 5
Data Requirements and Solution Procedure 6
Evaluation of the Model 7
  Validation 7
  Flow Patterns 9
Topography, Climatology, and Winds 13
Using the Model for Planning—A Case Study 13
Summary and Conclusions 15
Literature Cited 15
Appendix 16

Estimating Airflow Patterns Over Complex Terrain

Michael A. Fosberg, William E. Marlatt,
and Lawrence Krupnak

Introduction

Land managers are increasingly faced with problems requiring quantitative estimates of airflow patterns over complex terrain. Use of the wind information may range from potential air quality analysis for land use planning to predicting spread of actual wildfires. Areas in which such analysis is required are typically mountainous. Nearly always, evaluation is severely hampered by a single problem—lack of data, particularly wind data.

For these reasons, a method of determining boundary layer flow patterns is needed as an alternative to expensive data networks.

Boundary layer flow over complex terrain cannot currently be numerically modeled with complete fluid and thermodynamic equations. Accuracy and quantity of the initial data fields required for complete solution only shift the problem back to need for expensive data networks (Fosberg 1967, 1969). While these costs and efforts may be worthwhile in special locations and for specific problems, flexibility in geographic location and timeliness of solutions are sacrificed. We feel that an alternative procedure is required for wind pattern analysis which provides geographic flexibility and does not require sophisticated, expensive data networks. Such solutions cannot include all atmospheric processes, however. The governing equations must be simplified and some important effects must be represented by parameterized analogs.

A model of this type is based on tradeoffs between simplified solutions and preservation of realistic results. Several models of thermal and terrain-induced perturbation of near-ground flow have been developed recently. Anderson (1971) and Lantz[4] developed single layer models of two-dimensional potential flow over terrain features. Anderson (1971), Fosberg et al. (1972), and Fosberg[5] examined the thermally driven flow disturbances. These studies were all based on the philosophical argument that major simplification of the equations was acceptable, and that the disturbed flow field could be superimposed on a mean flow field. While superficially attractive, these preliminary models did not evaluate the consequences of the simplifications, nor did they provide quantitative arguments supporting neglect of specific processes.

Each of the models describes a single layer of finite depth, depicts a quasi-horizontal slab, and treats body forces as an impulse acceleration. The models also require the flow to be statically stable, either as an incompressible fluid or through the hydrostatic assumption. Superposition of disturbed flows on the mean flow also implies limitations on the processes that can be modeled. Impulse accelerations tacitly imply that a model is intended as a diagnostic tool rather than a time-dependent predictive model. Also, these models generally neglect or highly linearize the advection terms in the dynamic equations.

The highly idealized treatment of the advection term is probably the most serious of the assumptions. Justification is provided partially by examination of the energy integrals in Fosberg's (1967, 1969) analysis of flow over single ridges. Conversion of potential energy to kinetic energy dominates the kinetic energy budget. The advective redistribution of kinetic energy and the viscous dissipation are about an order of magnitude smaller. While these energy budget comparisons do not fully justify neglect of the advective processes, they do show that the assumption does not invalidate the models, but only restricts interpretation of the results.

---

[4] *Lantz, R. B. 1972. Application of a three dimensional numerical model to air pollution calculations. Preprint of paper presented at 65th Annu. Meet., Air Pollution Control Assoc., Miami Beach, Fla., June 18-22 22 p.*

[5] *Fosberg, Michael A. (in press). New technology for determining atmospheric influence on smoke concentrations. Proc. Int. Symp. on Air Quality and Smoke from Urban and For. Fires, 1973. 11 p.*

In general, this class of airflow models excludes the small-scale physical situations in which transient or highly interactive processes such as gravity waves or unstable thermal convection dominate the flow field. Also, because of the restrictions imposed on the advection terms, downwind wake effects are not properly represented.

Use of these simplified models—rather than complex and complete solutions or as a substitute for extensive field studies—becomes attractive when extensive data are not available, or in land use planning where alternatives may be great, the time span for planning short, and the accuracy or costs of more physically precise solutions and studies unwarranted.

The model described in this paper is intended to meet these applied objectives. This model is based on simplified solutions of the complete equations. It is philosophically identical to the preliminary models, but combines more of the physical processes.

Structure of the Model

The mathematical model is based on the terrain-induced flow processes derived by Anderson (1971) and the thermally induced flows described by Fosberg et al. (1972). In addition, the frictional terms are included in the model. Anderson's model was based only on a form of the divergence equation, while the Fosberg et al. (1972) model was based only on the vorticity equation. The model developed here is developed from both equations.

The advection terms were neglected in both previous equations. The consequences of this assumption are that the equations were simplified at the expense of losing a complete physical description of the dynamic processes. Thermally, frictionally and terrain-induced flows were superimposed on a background potential flow across the computational boundaries. Each of these disturbances was assumed to take place only within the computational area. Superposition of disturbances on the background flow, after neglecting advection terms, is physically analag
to an impulse acceleration. The diagnostic nat
of the model was achieved by allowing the impu
to act over a small, finite time interval defined
phase velocities of disturbances. Flow follow
the ground surface was obtained by a coordin
transform. A rigid upper surface above the
rain was assumed in order to define the top of
atmospheric slab.

Procedures for solving the equations invo
serial approximations which superimpose a m
physical effect on the previous solution. The fi
step in the solution was to transfer the large-sc
background wind into a terrain-induced modifi
tion of the throughflow. This step provided a lo
throughflow wind.

Next, thermal and frictional modification
the vorticity and divergence were introduc
These changes were superimposed on the terra
induced flow. Finally, stream functions and vel
ity potentials were calculated so that the wi
speed and direction could be defined at all inter
points.

Throughflow Representation

Total airflow through the computation fie
was required to satisfy conservation of ma
Since the lower surface of the layer was mounta
ous, provisions had to be made for local channeli
and deflection. Throughflow characteristics we
calculated from the steady-state mass continui
equation as outlined by Anderson (1971). Verti
integration and use of the anelastic approxim
tion permitted local velocities to be approximat
from the overall wind field and terrain featur
The steady-state continuity equation is:[6]

$$\nabla \cdot \rho \underset{\sim}{v} = - \frac{\partial(\rho w)}{\partial z}$$

In this equation, ∇ is the horizontal gradie
operator, ρ is density, $\underset{\sim}{v}$ is the velocity vect
and w is the vertical motion, positive upward.

Vector coordinates used in the mathemati
are west to east in the x direction, south to nor
in the y direction, and vertically as z.

The anelastic approximation, where kinemat
influences on density are negligible compared
thermodynamic influences, was first applied
the equation:

$$\overline{\rho}\ \nabla \cdot \underset{\sim}{v} = - \frac{\partial(\rho w)}{\partial z}$$

---

[6] *See appendix for a complete description of notations us
in the equations.*

Bars over a variable indicate a mean value for the slab. The equation was then integrated over the depth of the layer between the ground (h) and the top of the slab (H).

$$\bar{\rho}\int_h^H \nabla\cdot\underset{\sim}{v}\,dz = -\int_h^H \frac{\partial(\rho w)}{\partial z}$$

Horizontal divergence was defined as $\delta = \nabla \cdot \underset{\sim}{v}$ so that the integral equation was solved as:

$$\bar{\rho}\,\bar{\delta}\,(H-h) = -\rho w(H) + \rho w(h)$$

through the mean value theorem. A rigid lid was assumed, so $\rho w(H)$ became zero. Vertical motion near the ground was assumed to be dominated by orographic lifting. The horizontal divergence of the mean wind field then became:

$$\bar{\delta} = \frac{\rho}{\bar{\rho}}\,\underset{\sim}{v}\cdot\frac{\nabla h}{(H-h)} \qquad (1)$$

Terrain modification of the large-scale flow could then be calculated from the channeling and deflection of this flow, and could provide a first approximation of the local wind.

Thermal and Frictional Influences

Modification of the wind field produced by thermal acceleration and retardation required invoking the assumptions associated with the advection terms of the complete equations. Frictional influences were included as spatial variations of idealized and parameterized solutions relating surface characteristics to the wind profile. The fundamental procedure was to: (1) derive the complete divergence and vorticity equations, (2) judiciously neglect the advective terms, (3) allow full influence of the thermal terms, and (4) utilize classic frictional solutions.

The procedure required for inclusion of these body forces was to define the thermal and frictional solutions in terms of the Navier-Stokes equations. The first step was to express the divergence equation utilizing these assumptions. Divergence was obtained through:

$$\nabla\cdot\frac{d\underset{\sim}{v}}{dt} = \frac{\partial\delta}{\partial t} = \nabla\cdot(-c_p\Theta\nabla p_*) + \nabla\cdot(K\nabla^2\underset{\sim}{v})$$

where θ is the potential temperature, p_* is the pressure variable defined as $p_* = T/\theta$, and K is the turbulent viscosity. The friction term was simplified to:

$$\nabla\cdot K\left(\frac{\partial^2 \underset{\sim}{v}}{\partial z^2}\right) = K\left(\frac{\partial^3 u}{\partial x\partial z^2} + \frac{\partial^3 v}{\partial y\partial z^2}\right)$$

since the horizontal dissipation terms are small compared to the vertical terms when expressed in finite-difference mesoscale models. A parameterized form of the dissipation was obtained from the logarithmic wind profile near the ground. The wind profile for an adiabatic surface layer (Sutton 1953) is:

$$\frac{\partial u}{\partial z} = \frac{u_*}{kZ^2} \quad\text{and}\quad \frac{\partial v}{\partial z} = \frac{v_*}{kZ^2} \qquad (2)$$

where u_* and v_* are the friction velocities and k is the von Karman constant. These two functions were differentiated with respect to z to produce the second derivative. The terms

$$\frac{\partial^2 u}{\partial z^2} = -\frac{u_*}{kZ^2} \quad\text{and}\quad \frac{\partial^2 v}{\partial z^2} = -\frac{v_*}{kZ^2}$$

were then substituted into the divergence equation. The divergence equation then became:

$$\frac{\partial\delta}{\partial t} = -c_p\Theta\nabla^2 p_* - c_p\nabla\Theta\cdot\nabla p_* - \frac{K}{kZ^2}\left(\frac{\partial u_*}{\partial x} + \frac{\partial v_*}{\partial y}\right) \qquad (3)$$

Friction velocity was obtained by integrating the wind profile equation for fully rough surfaces. The friction velocities are then:

$$u_* = \frac{|\bar{u}|\,k}{\ln\left(\dfrac{Z + z_o}{z_o}\right)} \qquad (4a)$$

$$v_* = \frac{|\bar{v}|\,k}{\ln\left(\dfrac{Z + z_o}{z_o}\right)} \qquad (4b)$$

where z_o is the surface roughness length and Z is the height of the wind above ground.

Rotational flow characteristics were introduced through the vorticity equation. Using the same assumptions for this derivation as were used in the development of the divergence equation, the vorticity equation became:

$$k\cdot\nabla x \frac{d\underset{\sim}{v}}{dt} = \frac{\partial\zeta}{\partial t} = -c_p \frac{\partial(\Theta,\ p_*)}{\partial(x,\ y)} \qquad (5)$$

$$-(\zeta+f)\ \delta - \frac{K}{kZ^2}\left(\frac{\partial v_*}{\partial x} - \frac{\partial u_*}{\partial y}\right)$$

The divergence and vorticity equations are time-dependent and therefore must be integrated. Divergence was integrated directly through the mean value theorem over an arbitrary time interval. Since little is known about the rate of change of divergence, a square wave impulse of interval Δt_δ was assumed. The integrating time factor then became $\frac{1}{2}\Delta t_\delta$ when the magnitude of the acceleration was assumed to be ½ the observed or maximum value. Divergence was then:

$$\partial = \tfrac{1}{2}\Delta t\delta \left[-c_p\Theta\nabla^2 p_* - c_p\nabla\Theta\cdot\nabla p_* \qquad (6)\right.$$

$$\left. - \frac{K}{kZ^2}\left(\frac{\partial u_*}{\partial x} + \frac{\partial v_*}{\partial y}\right)\right] + \bar{\delta}$$

Given this solution, the vorticity equation became the ordinary differential equation of:

$$\frac{\partial\zeta}{\partial t} + \zeta\delta = -c_p \frac{\partial(\Theta,p_*)}{\partial(x,y)} - f\delta$$

$$- \frac{K}{kZ^2}\left(\frac{\partial v_*}{\partial x} + \frac{\partial u_*}{\partial y}\right)$$

The solution is:

$$\zeta = e^{-\int\delta dt}\int\left[-c_p \frac{\partial(\Theta,p_*)}{\partial(x,y)} - f\delta\right.$$

$$\left. - \frac{K}{kZ^2}\left(\frac{\partial v_*}{\partial x} - \frac{\partial u_*}{\partial y}\right)\right] \exp\ (\int\delta dt)dt$$

$$+\ ce^{-\int\delta dt}$$

Again, an impulse of finite time interval Δt_ζ w
assumed, so that the mean value integration ga

$$\zeta = \exp(-\tfrac{1}{2}\delta\Delta t_\zeta)\ \tfrac{1}{2}\Delta t_\zeta$$

$$\left[-c_p \frac{\partial(\Theta,p_*)}{\partial(x,y)} - f\delta - \frac{K}{kZ^2}\left(\frac{\partial v_*}{\partial x} - \frac{\partial u_*}{\partial y}\right)\right.$$

$$\exp(\tfrac{1}{2}\delta\Delta t_\zeta) + ce^{-\delta\Delta t_\zeta /}$$

The arbitrary time intervals for the diverger
and vorticity were defined in terms of pha
velocities. Because a rigid lid was used as an upp
boundary for the calculation and an anelastic a
proximation was used for compressibility, t
phase velocity for divergence was taken as t
speed of sound. This gave a time interval of:

$$\Delta t_\delta = \frac{\text{sec}\ \Delta}{300\ \text{m}}$$

where Δ is the minimum distance between comp
tational points. Phase velocities for vorticity we
taken to be the large-scale windspeed, so that t
time interval for vorticity was:

$$\Delta t_\zeta = \frac{\Delta}{(u^2 + v^2)^{\frac{1}{2}}}$$

For typical distances of 1 to 10 km between co
putational points and windspeeds of 1 to 10 m p
second, the time interval is of the order of 1,0
seconds. Divergence at the mesoscale is typical
10^{-5} to 10^{-3} per second. These magnitudes su
gested the exponential term in the vorticity equa
tion should be approximately one, except unde
condition of light winds and large grid spacin
The constant of integration was then taken to
the large-scale flow vorticity. The vorticity the
became:

$$\zeta = \tfrac{1}{2}\Delta t_\zeta \left[-c_p \frac{\partial(\Theta,p_*)}{\partial(x,y)} - f\delta \right. \qquad ($$

$$\left. - \frac{K}{kZ^2}\left(\frac{\partial v_*}{\partial x} - \frac{\partial u_*}{\partial y}\right)\right] + \zeta$$

Equations (1) and (6) for the frictionall
thermally and terrain-induced flow deviations
divergence, and equation (7) for the frictional
and thermally induced flow deviations on rotatio
were then used to calculate the wind component

Calculation of Local Winds

Wind components of the flow were calculated in the area by superimposing the terrain, frictional, and thermal deviations on the large-scale wind. The wind deviations were obtained by separating the flow into an irrotational divergent component and a nondivergent rotational component. The divergent flow was described with a velocity potential and the rotational component with a stream function. The deviation velocity was then:

$$\underset{\sim}{v} = \underset{\sim}{k}x\nabla\psi + \nabla\phi$$

where ψ is the stream function and ϕ is the velocity potential. The vorticity is:

$$\zeta = k\bullet\nabla x\underset{\sim}{v} = \underset{\sim}{k}\bullet\nabla x\underset{\sim}{k}x\nabla\psi + \underset{\sim}{k}\bullet\nabla x\nabla\phi = \nabla^2\psi \quad (8)$$

and the divergence is:

$$\delta = \nabla\bullet\underset{\sim}{v} = \nabla\bullet\underset{\sim}{k}x\nabla\psi + \nabla\bullet\nabla\phi = \nabla^2\phi \quad (9)$$

Since the vorticity and divergence were known from equations (1), (6), and (7), the stream function and velocity potential could be obtained from a numerical solution of the elliptical differential equations (8) and (9). Decomposing the velocity into the west-east component and the south-north component, and superimposing the background flow, the velocities are:

$$u = u_o + \frac{\partial\phi}{\partial x} - \frac{\partial\psi}{\partial y} \quad (10a)$$

and

$$v = v_o + \frac{\partial\phi}{\partial y} + \frac{\partial\psi}{\partial x} \quad (10b)$$

where u_o and v_o are the background velocities.

Flow Near the Ground Surface

Airflow along the terrain surface is of much more interest in fire or air-quality studies than flow at some fixed elevation. Since the equations require calculations to be made on a flat horizontal surface, transformations from the horizontal plane to the terrain surface are necessary.

Data required by the model are observed at a fixed height above the ground (generally between 1 and 3 m) so the transforms chosen were to restructure the observed data to a flat surface locally, and then to consider the model as being composed of a series of adjacent horizontal surfaces, each of slightly different elevation based on the elevation of the local terrain. The coordinate transform required expressing the derivations of the variables observed on the terrain surface as though they were along a horizontal surface. If vertical variations of the variables are known, the transform for any quantity, S, is then:

$$\left.\frac{\partial S}{\partial x}\right)_E = \left.\frac{\partial S}{\partial x}\right)_T - \left.\frac{\partial S}{\partial z}\frac{\partial h}{\partial x}\right)_T$$

where the unsatisfied parentheses indicate derivations taken along either constant elevation or along the terrain surface.

Second derivations were obtained similarly as:

$$\left.\frac{\partial^2 S}{\partial x^2}\right)_E = -2\frac{\partial^2 S}{\partial x\,\partial z}\frac{\partial h}{\partial z} - \frac{\partial S}{\partial z}\frac{\partial^2 h}{\partial x^2}$$

$$+ \left(\frac{\partial h}{\partial x}\right)^2 \frac{\partial^2 S}{\partial_z^{\,2}}$$

The higher order terms involving derivatives of the terrain are small compared to the linear term. Six separate derivatives of the thermal characteristics are required by the vorticity and divergence equations. These are the first derivative of potential temperature and pressure, and the second derivative of pressure in the cardinal directions.

Vertical variations of these thermodynamic variables are required. These were obtained first for potential temperature through static stability for a hydrostatically balanced atmosphere as:

$$\left.\frac{\partial\Theta}{\partial x}\right)_E = \left.\frac{\partial\Theta}{\partial x}\right)_T - \Theta\sigma\left.\frac{\partial h}{\partial x}\right)_T \quad (11a)$$

$$\left.\frac{\partial\Theta}{\partial y}\right)_E = \left.\frac{\partial\Theta}{\partial y}\right)_T - \Theta\sigma\left.\frac{\partial h}{\partial y}\right)_T \quad (11b)$$

where $\sigma = \frac{1}{\theta}\ \frac{\partial\theta}{\partial z}$.

Vertical decrease of pressure was represented by hydrostatic equilibrium:

$$\frac{\partial p_*}{\partial z} = -\frac{g}{c_p\Theta}$$

Utilizing these relationships, the pressure derivatives are:

$$\left.\frac{\partial p_*}{\partial x}\right)_E = \left.\frac{\partial p_*}{\partial x}\right)_T + \left.\frac{g}{c_p \Theta}\frac{\partial h}{\partial x}\right)_T \tag{11c}$$

$$\left.\frac{\partial p_*}{\partial y}\right)_E = \left.\frac{\partial p_*}{\partial y}\right)_T + \left.\frac{g}{c_p \Theta}\frac{\partial h}{\partial x}\right)_T \tag{11d}$$

$$\left.\frac{\partial^2 p_*}{\partial x^2}\right)_E = \left.\frac{\partial^2 p_*}{\partial x^2}\right)_T - 2\left.\frac{g}{c_p \Theta^2}\frac{\partial h}{\partial x}\frac{\partial \Theta}{\partial x}\right)_T \tag{11e}$$

$$\left.\frac{\partial^2 p_*}{\partial y^2}\right)_E = \left.\frac{\partial^2 p_*}{\partial y^2}\right)_T - 2\left.\frac{g}{c_p \Theta^2}\frac{\partial h}{\partial y}\frac{\partial \Theta}{\partial y}\right)_T \tag{11f}$$

Horizontal derivatives of the friction velocities remain unchanged, since the model is designed for use in the constant flux layer where they are constant in the vertical. This shallow layer assumption then gives:

$$\left.\frac{\partial u_*}{\partial x}\right)_E = \left.\frac{\partial u_*}{\partial x}\right)_T \tag{11g}$$

$$\left.\frac{\partial u_*}{\partial y}\right)_E = \left.\frac{\partial u_*}{\partial y}\right)_T \tag{11h}$$

$$\left.\frac{\partial v_*}{\partial x}\right)_E = \left.\frac{\partial v_*}{\partial x}\right)_T \tag{11i}$$

$$\left.\frac{\partial v_*}{\partial y}\right)_E = \left.\frac{\partial v_*}{\partial y}\right)_T$$ (1

These linear coordinate transforms neglect t small changes in the grid spacing due to slc distances projected to the horizontal grid.

Data Requirements and Solution Procedure

Specific data required by the model are te perature, pressure, elevation, and roughn length of the underlying surface for all compu tional points. Temperature and pressure data a transformed thermodynamically to model va ables by:

$$\Theta = \frac{T}{p_*}$$ (

and

$$p_* = \left(\frac{p}{p_o}\right)^{\frac{R}{c_p}} = \left(\frac{p}{p_o}\right)^{0.2857}$$ (1

where p_o is a reference pressure and T is express in an absolute temperature scale. While any co sistent set of units may be used, the appendix li of symbols gives constants only in metric units.

Roughness lengths are a reasonably consta value describing the height at which the me wind flow is zero. These values are convenient describable to acceptable accuracy by classifyi the surface into such categories as (but not limit to) grass, brush, boulder field, and so forth. The data are tabulated in numerous texts (Sutt 1953, Priestley 1959, and Sellers 1965); a samp listing is provided in table 1 for convenience a completeness.

Table 1.--Relationship between surface roughness and surface features

Classification of underlying surface	Typical value of roughness length (z.)	
	cm	
Mud flats, ice	0.001	(Sutton 1953)
Smooth snow	0.005	(Priestley 1959)
Snow, prairie	0.01	"
Thin grass up to 50 cm high	5	(Sutton 1953)
Thick grass up to 50 cm high	9	"
Wheat	22	(Sellers 1965)
City	165	"
Orchard	198	"
Fir forest	283	"

Since the model was designed for use in moderately small areas of finite size, several single-valued coefficients are required to complete the model. Most important of these are the static stability and the large-scale wind direction and windspeed. The large-scale winds were specified as the geostrophic wind. Less important coefficients are the eddy viscosity, the latitude (if the geographic scale of a particular solution is large so that the earth's rotation is important), and the large-scale vorticity (if strong curvature exists in the large-scale flow).

Wind patterns are calculated from a sequence of approximations, each refining the previous step by introducing a more refined physical process, and superimposing the refinement on the previous solution. The first step was to transfer the large-scale background wind into a major terrain-induced modification of the throughflow. This step provided a local throughflow wind.

First, the divergence was calculated through equation (1) for a smoothed terrain. This smoothed terrain was obtained by averaging the four surrounding points with each computational point; the rigid lid was placed well above the terrain in this step. Second, the terrain-induced vorticity was calculated by equation (7) with the thermal and frictional terms neglected. Once these vorticities and divergences were calculated, they were transformed to stream functions and velocity potentials through numerical solutions of equations (8) and (9), and subsequently resolved into velocities by equation (10). These first approximations to the wind field represented the influences of the large terrain feature on the throughflow.

The second level of approximation involved recalculating the terrain-induced divergence for a shallow layer. Divergence was calculated by equation (1) for the actual terrain.

The next step required using the large-scale terrain flow to calculate the friction velocities by equations (4a and 4b) and making the coordinate transforms of equation (11). These intermediate steps provided the input to the final level of approximation.

Friction terms, defined by the friction velocity, and the spatial derivations of temperature and pressure after the coordinate transform were included in the solution of equation (6) for divergence and of equation (7) for vorticity. Background divergence came from the second level of approximation, and the background vorticity came from the divergence and vorticity as in the first step through numerical solutions of equations (8) and (9). Velocity components were then calculated through equation (10), where the background velocities were defined by the first step.

Evaluation of the Model

Validation

There are several philosophies of model validation, each designed to accomplish specific objectives. Because this model is intended for use in applied meteorology, we have chosen to use actual data sets from mountain mesoscale studies to validate the wind field estimates. In adopting this approach, we have imposed a severe test since the model is limited in spatial resolution by computational filtering to approximately four times the grid distance, while the validation data have small-scale spatial resolutions defined by nearby terrain or vegetation and sensor response characteristics. Also, calculated winds represent an average wind over an area defined by the grid mesh. Such a test is desirable, however, because it defines operational uncertainty rather than model potential, and represents actual resolution attainable.

Seven data sets were used in the model validation. Six came from studies conducted by Cramer[7] in the Oregon Cascade Mountains. One data set came from central California (Fosberg and Schroeder 1966). All seven depict daytime conditions: five for midafternoon, and two for morning. One morning case occurred under overcast skies and rain. The other six occurred with strong solar heating. Background winds ranged from 2 to 5 m per second. The Oregon winds were calculated on a 6 km square grid, the California case on a 16 km square grid. Air temperatures were extrapolated to grid points from the field network weather stations.

Evaluation of the errors in both windspeed (fig. 1) and wind direction (fig. 2) demonstrates the utility of the model. The root mean square windspeed error was 2.0 m per second. Forty-five percent of the calculated windspeeds fell within 1 m per second of the observed wind, and 75 percent fell within 2 m per second. These comparisons were made over an observed range of 0.5 to 10.5 m per second. Observed wind directions were reported on a 16-point compass basis. Therefore, the error analysis is presented as a compass-point error rather than a more precise evaluation

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[7] We thank Owen P. Cramer of the U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon for unqualified use of original data for the model validation and for permission to reproduce unpublished results in this paper.

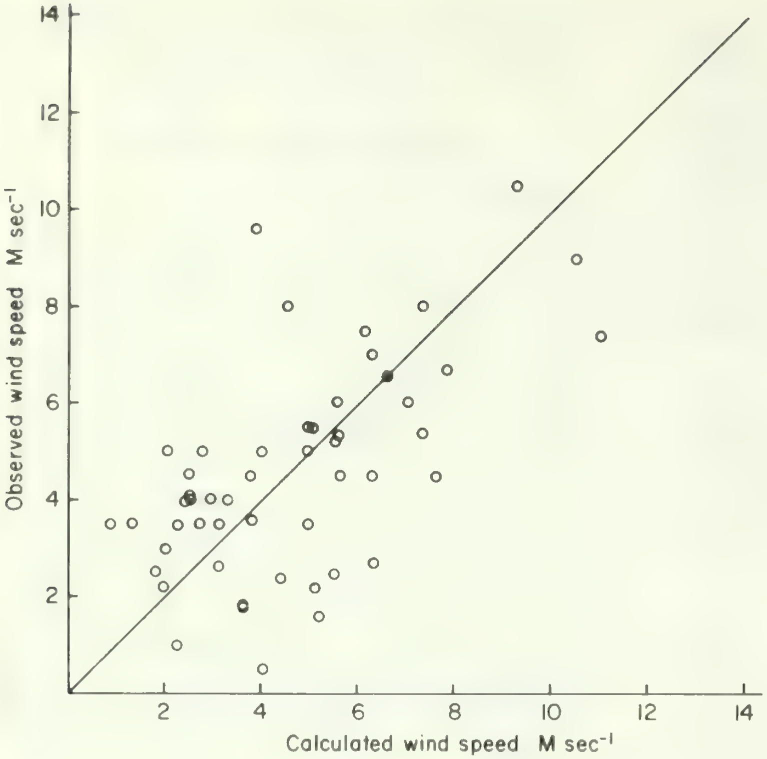


Figure 1.—Comparison of calculated a observed windspeeds. Bold diagonal li defines perfect fit. Forty-five percent predictions fall within 1 m sec^{-1} of t observed windspeed and 75 percent f within 2 m sec^{-1}

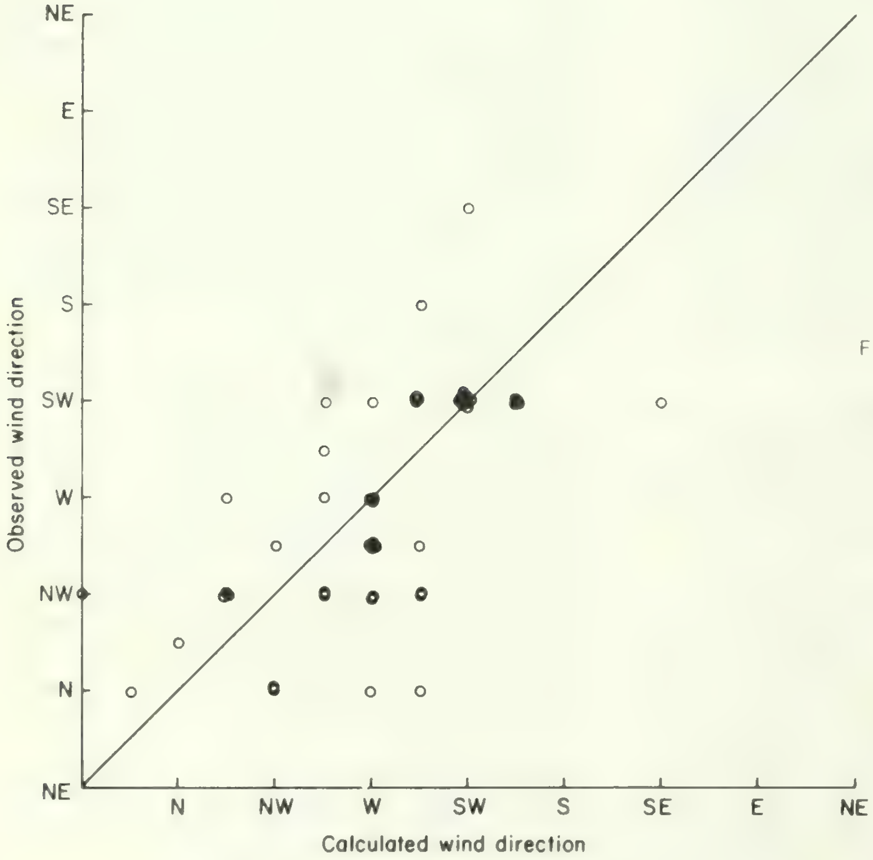


Figure 2.—Comparison of calculated a observed wind direction. Comparison on a 16-point compass basis. Sixty pe cent of calculated directions fall with 11 degrees and 92 percent fall with 22 degrees of observed directions

of angle. The root mean square direction error was 1.9 points. Sixty percent of the calculated directions fell within 1 compass point of the observed direction, and 92 percent fell within a 2-point envelope of the observed direction. Observed directions were from all compass points except for the east and northeast sections.

Models of this type implicitly require a number of specifiable coefficients which tune the model to particular geographic regions. While we have attempted to specify these coefficients through physical arguments, some are still at the discretion of the user. The integration coefficients were totally predetermined. The rigid lid coefficients for potential flow were selected through several criteria. The first was that the terrain could not penetrate the rigid lid. The second was based on a large number of solutions where the lid was systematically varied until a high level of sensitivity was reached. Lid height is based on elevation differences across the grid field. The user guidelines in the climatology section of this paper describe the techniques for determining layer thickness. They are cited here because the consequences are reflected in the error analysis.

Flow Patterns

Each of the seven cases showed similar dynamic processes (table 2). Thermally and terrain-produced divergence dominated the dynamics of the flow. Divergence-generated flow perturbations were 2.5 to 4.3 times as large as vortically generated deviations. Vortex flow accounted for 11 to 24 percent of total kinetic energy, while 32 to 69 percent was accounted for by the potential flow. Strongest local wind energetics were observed under conditions of light background winds and strong surface heating. As background winds increased, or the solar heating decreased, the local winds became a weaker component and less important in the total kinetic energy budget. Tests of background windspeeds for several hypothetical cases beyond the range of data used in validation show that at 0.5 m per second, the wind patterns are controlled completely by the thermal patterns. At 10 m per second, thermal control vanished and terrain influences were weak.

Mesoscale flow characteristics are best illustrated through a detailed examination of one of the case studies. The area is in the Oregon Cascades, south of Mt. Hood, north of Mt. Jefferson, and runs from the Willamette Valley across the crest of the Cascade Range to the edge of the eastern Oregon plateau. The mountains are penetrated by a major drainage on the west side, the Clackamas River. The particular case selected, August 8, 1963 at 1600 PST, was chosen as representing a typical or intermediate situation. The synoptic weather pattern was characterized by a weak upper-level, high-pressure area, and west to west-north-west geostrophic surface flow over the Cascades. Details of the observation and analysis procedures were presented in Cramer (1972) and Cramer and Lynott (1961, 1970). Discussion here is limited to resultant computations and estimation of the wind field from the analysis. Only salient features of Cramer's analysis are presented here for completeness.

Cramer's data analysis of temperature and 850 mb surface heights were interpolated to 6-km grid points. These data were converted to potential temperature and normalized station pressures for each grid point. Terrain elevation at each grid point was interpolated from a topographic map.

Table 2.--Relationship between flow energetics and weather features

Date	Location	Time	Flow energy accounted for by:		Ratio of irrotational energy to rotational energy	Geostrophic windspeed	Weather features
		LST	Irrotational energy	Rotational energy			
			percent			*m per second*	
1963							
Aug. 8	Oregon	0700	60.4	24.3	2.5	2.5	Strong morning heating
Aug. 8		1600	55.1	19.8	2.8	2.5	Strong afternoon heating
Aug. 19		0700	34.2	9.1	3.8	4.9	Weak morning heating--extensive clouds and rain
Sept. 4		1600	31.5	10.7	2.9	4.9	Strong afternoon heating
Sept. 5		1600	42.7	15.7	2.7	3.5	Strong afternoon heating
Sept. 12		1300	68.5	20.7	3.3	2.5	Strong afternoon heating
1962							
Aug. 15	Calif.	1400	42.3	9.9	4.3	3.0	Strong afternoon heating

The underlying surface was almost exclusively characterized by conifer forest, so the roughness length was taken as a constant 283 cm.

Temperature distribution (fig. 3) over this terrain generally showed a slight decrease with elevation. West-facing slopes were warmer than east-facing slopes. The major river valley was much warmer than surrounding areas, and provided strong local temperature gradients. In general, the area east of the Cascades was warmest as a result of morning heating and topographic blocking of cool marine air flowing off the Pacific Ocean.

Height of the 850 mb pressure surface (fig. 4) generally reflected the high-pressure area over northwest Oregon. Surface heating of the mountain slopes produced the "thermal low" frequently observed along the West Coast. This "thermal low" appeared as a mesoscale low-pressure area through the higher terrain and modified the large-scale pressure pattern.

These observed data were transformed to the thermodynamic variables of potential temperature and normalized nondimensional surface pressure used in the model equations. The 850 mb surface height was reduced to the terrain surface through the hydrostatic equation using the static stability from the Salem, Oregon rawinsonde observation. Once this pressure calculation was made, the potential temperatures were calculated with these pressures and the interpolated temperatures.

Since the dynamic influences due to pressure gradients are completely reflected in the 850 mb pressure surface height, only the potential temperature patterns will be described here (fig. 5). Potential temperature showed a highly organized pattern. Higher elevations had higher potential temperatures. Valleys where cooler marine air could penetrate from the coast were clearly marked by low potential temperature. East-slope highlands had highest potential temperatures.

These observed fields of temperature and pressure were used to calculate the fundamental kinematic characteristics of divergence and vorticity. Divergence patterns were strongly correlated with terrain. Even small topographic features such as narrow ridges and valleys stand out in the divergence patterns (fig. 6). Flow divergence was confined to lowlands and valley bottoms. Convergence zones were on ridgetops and followed the terrain contours. Gentle slopes and large continuous upland areas on the east slopes typically had weak gradients. Magnitudes of the divergence were typically $\pm 10^{-3}$ per second. The convergence areas in regions of rugged terrain were much smaller than divergence areas, and maximum values were two to three times as intense as the compensating divergent areas. T intense gradients generated in the rugged t rain were most noticeable between the Clackam River valley and the surrounding ridges. Areas moderately changing terrain had divergent a convergent patterns of roughly equal area a intensity.

Vorticity patterns (fig. 7) did not show eith the response to small terrain features or the lar magnitude found in the divergence fields. V ticity was typically $\pm 10^{-5}$ per second with t strongest areas only $\pm 10^{-4}$ per second. Ridgeto tended to have anticyclonic relative vorticity 10^{-4} per second while valley bottoms had cyclon vorticities of -10^{-4} per second. Areas with slow changing elevation did not show a consiste terrain-vorticity correlation. In general, vortici tended to have a much longer wave length th divergence. The only generalizations we can ma about the patterns are that major ridges tend favor anticyclonic vorticity, while lowlands a major valleys tend to favor cyclonic vorticit This characteristic was probably due to the dom nant influence of the divergence in flow properti

Resultant wind fields (fig. 8) showed stro topographic and thermal control of the wind pa terns. Airflow in the Clackamas River valley a the other two west-slope watersheds penetratin into the Cascades showed strong topograph channeling up the rivers and the influence of slo winds angling away from the valley axis. We slope areas away from these major drainag generally showed upslope flow, even on the l sides. Strongest winds were calculated on hig ridgetops and at the heads of canyons as th reached the highlands. Lee effects were mo noticeable along the eastern slope. Winds flowin across the ridge in the northeast portion of t area were reduced from 5 m per second to 1 m p second by the upslope influences on the lee sid Strong, thermally driven winds were calculat in the south-central and southeastern portion the area, where prevailing winds were reduced a influences of the penetrating west-slope canyon were negligible. Those variables which had grea est impact on model reliability were determin by sensitivity analysis. Both processes and va ables were systematically excluded and err analysis conducted on all seven cases. This anal sis indicated that frictional influences and t vorticity equation affected the resultant win field only slightly. Terrain and thermal influenc totally dominated the calculations. Neglect either created large errors in the wind field in t test cases. Further analysis of these process indicated that pressure variation could be e cluded with introduction of a small error, but th

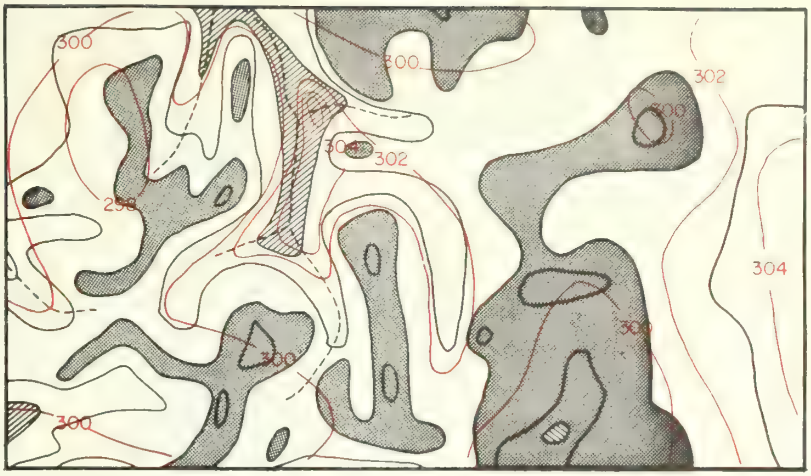


Figure 3.—Temperature field for 1600 PST, August 8, 1963. Temperatures are in degrees k; warmest areas are on the east slopes of the Cascade Mountains.

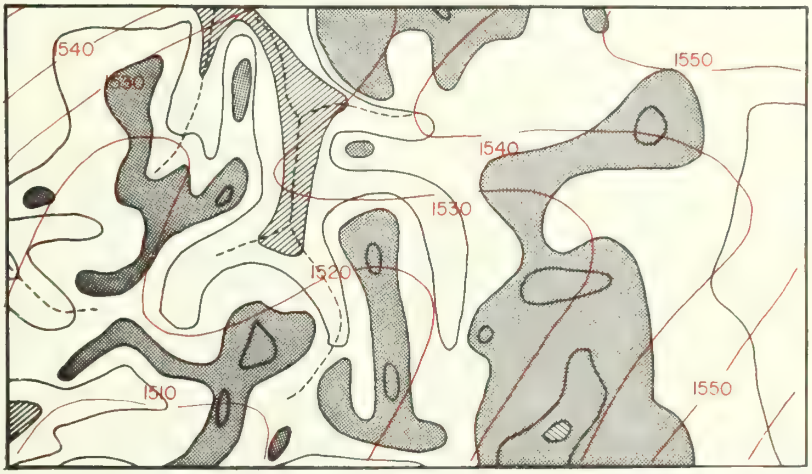


Figure 4.—Height of 850 mb surface for 1600 PST, August 8, 1963. Height is in meters above m.s.l. Thermal trough is oriented southwest to northeast.

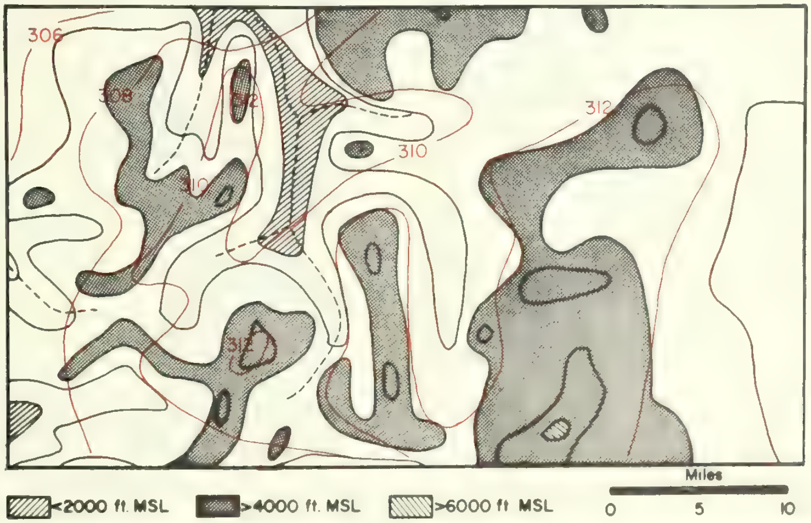


Figure 5.—Distribution of potential temperature for 1600 PST, August 8, 1963. Temperatures are in degrees k. Inversion of marine air into the mountains is confined to the Clackamas River valley.

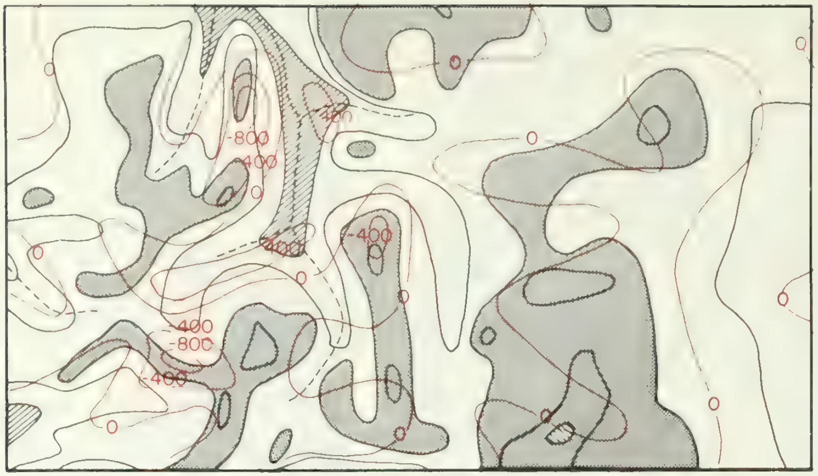


Figure 6.—Horizontal divergence field for 1600 PST, August 8, 1963. (Units are 10^{-5} sec^{-1}.) Strongest gradients of divergen between the west side drainages and the surrounding ridges.

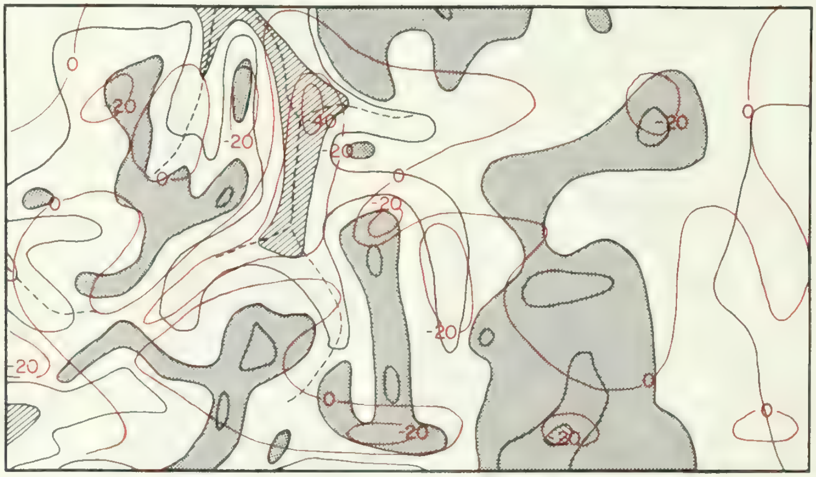


Figure 7.—Vertical component of vorticity for 1600 PST, August 8, 1963. (Units are 10^{-5} sec^{-1}.) Anticyclonic vorticity is on ridg and cyclonic vorticity is in valleys.

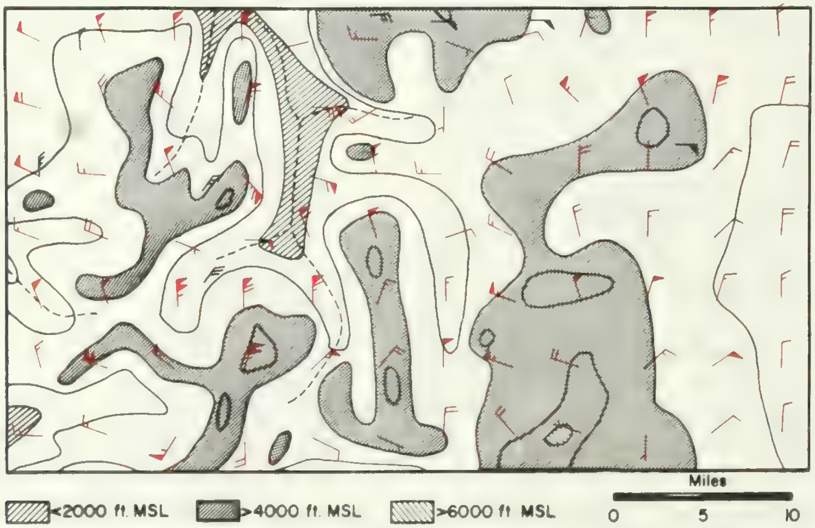


Figure 8.—Calculated and observed wind field for 1600 PST, August 8, 1963. Arrows indicate direction of wind. Speeds ar by sum of barbs and pennants on arrow tails. Pennants indicate 5 m sec^{-1}, a full barb, 2 m sec^{-1}, a half barb, 1 m sec^{-1}. Cal wind field is in red; observed wind field is in black.

the topographic and temperature field must be represented in complete detail for the model to provide realistic and verifiable results.

Topography, Climatology, and Winds

Two parameters are required if the model is to define the topographic influence on throughflow. The first of these, the depth of the rigid lid at the top of the slab, should normally be expected to be 1,500 to 2,000 m above the spatially smoothed terrain. The second parameter, the thickness of the shallow layer, refines the first estimate of terrain influences. It is 1.25 times the difference between the smoothed terrain and the actual terrain. These guidelines for the relationship between throughflow and terrain were determined from a large number of test cases where the coefficients were varied systematically. The final choice was a judgment of which relationships produced the most acceptable resultant wind field.

Grid point spacing is also related to topographic variations. In rugged terrain, a closely spaced grid is required to resolve the local winds, while in gently rolling terrain, a low-resolution grid will give acceptable wind fields. Guidelines for selecting appropriate grid spacing were developed from procedures similar to those used in evaluating layer thicknesses.

Numerous analyses were carried out with the same data sets so that performance could be evaluated by overall resultant wind field errors. Grid spacings between 1 and 6 km were evaluated for maximum terrain differences of 300 to 1,500 m. These analyses indicated that grid spacing should be reduced by 1 km for every increase in terrain range of 300 m. If the terrain within an area 10,000 km square varies by 300 m or less between the highest and lowest spatially averaged elevations, then a 6-km grid would be appropriate. If, on the other hand, the terrain variation were 1,500 m a 1-km grid would be appropriate. These spacings must be modified to the smallest grid spacing if the wind field is intended to be used for fine-scale analysis of pollution patterns or fire spread, or to larger spacing if broad geographic coverage is required. Grid spacing of 500 m is probably the minimum the model will treat properly. Close grid spacing does not permit a 50- by 50-point grid to include major terrain features. These two nonmodel dependent factors (terrain complexity and computer resources) must be considered in selecting the grid interval. The spacings specified here represent maximum spacing—not optimum for any particular application.

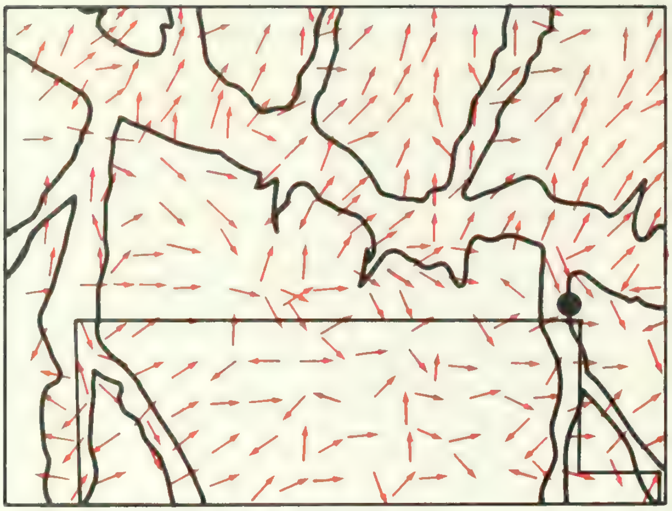
The seven cases in this analysis all came from detailed mesometeorological research studies. Such intensive data would not normally be available. Detailed temperature patterns can be estimated from climatological relationships developed for slope temperatures. Super and Grainger (1969) and Hayes (1941) made detailed studies of slope temperatures by aspect and time of day. Baker (1944), using maximum and minimum temperatures, characterized the slope temperatures for 20 mountainous areas of the Pacific and Rocky Mountain States. These climatological relationships will approximate the temperature distribution when the available observations and topography are used to fine tune the slope functions.

Using the Model for Planning—A Case Study

Consider a case where engineers and architects are designing a new plant at a mine mouth. The mineral extraction process will create a large volume of tailings over a period of years. These tailings could be hot. In the design study the questions are asked: (1) What will be the effect of changing the terrain in the immediate area by filling the gulches and small valleys with tailings on the downwind dispersal of stack contaminants?, and (2) What will be the effect on downwind dispersal if the tailings are approximately 70°C warmer than the surrounding areas?

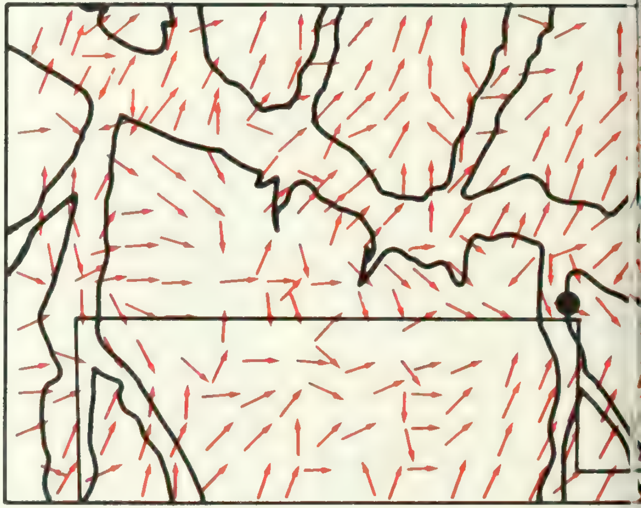
The wind model may be used to estimate probable consequences of the mining activity on pollution dispersal patterns. To illustrate this use, we assumed a light wind of 0.45 m per second (1 mile per hour) from the southwest; temperature distribution was given by climatology for nighttime conditions. Wind patterns before construction showed well-organized drainage flow into and down the valleys and gulches (fig. 9).

Two cases of land change were simulated to anticipate influence on the local wind patterns. In the first case, the valleys and gulches were filled with heated tailings. Changes in the flow were calculated near the modified landform. Heated areas increased the windspeeds and changed the directions to a uniform south-southwest flow down the major gulch (fig. 10). Airflow in the large river drainage to the north was turned and flowed up canyon. The second case considered was that the same gullies and canyons were filled with tailings, but the tailings were not heated. This modification also increased and organized the drainage flow (fig. 11). Winds were from the southwest over the tailings for this case. How-



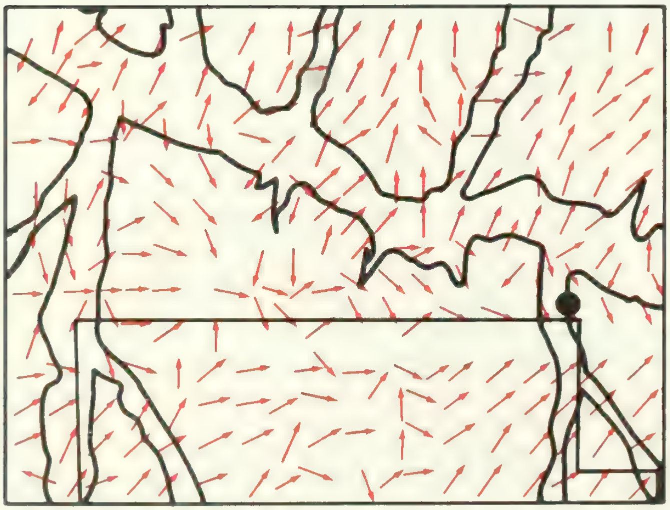
● indicates plant and mine site.

Figure 9.—Local wind pattern before construc
of a hypothetical plant and mine tailings.



● indicates plant and mine site.

Figure 10.—Simulated wind field for a case with heated tailings.



● indicates plant and mine site.

Figure 11.— Simulated wind field for a case w
cold tailings.

ever, air did not flow up the canyon from the major river drainage. The two cases predicted increases in windspeed of as much as 1 m per second and direction changes of 180 degrees near the planned mine activities.

Summary and Conclusions

Local thermally driven flows such as mountain and valley winds are simulated reasonably well. Interactions of these local flows, and influence of the larger scale potential flow on these local winds, are also included in the resultant flow. These thermally driven flows are determined properly primarily because the thermal forcing processes are stationary and locked to the terrain features. Also, these thermal features are in a quasi-steady state for several hours. Thus, neglect of the advective process is permissible, and the impulse integration to steady state approximates the flow field.

Thermal modification of potential flow across the terrain features dominates the driving forces. Potential flow was three times as important as rotational flow.

Error analysis of seven case studies and the application example indicated that the model could be used as an aid in fire and air-quality programs because of the low data requirements and the reduced computer effort required.

The wind model developed here was based on simplifications of the complete set of equations governing atmospheric flow over complex terrain. These simplifications imposed several limitations on the use of the model, both in types of flow that can be depicted and in spatial coverage of the solutions. Moving flow systems and flows which are characterized by intermittency or by separation are explicitly excluded, because (1) advection was eliminated, and (2) the model is intended to depict quasi-steady state processes. Coefficients describing static stability and overall wind throughflow place spatial limits on the model because (1) constant static stability prohibits larger scale baroclinicity, and (2) the single-valued wind vector prohibits large-scale flow discontinuity. Also, the neglect of advective processes excludes strong interaction of the mesoscale with larger scales, and does not allow for modification of the downwind environment.

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APPENDIX

List of Symbols

Symbol	Definition	Units
c_p	Specific heat at constant pressure	1.003 joules gm^{-1} $^{O}K^{-1}$
f	Coriolis parameter	sec^{-1}
g	Acceleration of gravity	9.8 m sec^{-2}
H	Thickness of rigid lid layer	m
h	Thickness of second approximation to flow	m
k	von Karman constant	0.4
$\underset{\sim}{k}$	Unit vector in vertical direction	dimensionless
K	Turbulent viscosity	m^2 sec^{-1}
p	Pressure	dynes cm^{-2}
p_o	Reference pressure	10^6 dynes cm^{-2}
p_*	Non-dimensional pressure $\left(\frac{p}{p_o}\right)^{\frac{R}{c_p}}$	----------
R	Ideal gas content	0.287 joules gm^{-1} $^{O}K^{-1}$
T	Temperature	Deg K
t	Time	Sec
$u, \bar{u}, u_o$	Windspeed in west to east direction	m sec^{-1}
u_*	Friction velocity in west-east direction	m sec^{-1}
$\underset{\sim}{v}$	Horizontal velocity vector	m sec^{-1}
$v, \bar{v}, v_o$	Windspeed in south-north direction	m sec^{-1}
v_*	Friction velocity in south-north direction	m sec^{-1}
w_w	Vertical windspeed	m sec^{-1}
x	Horizontal coordinate in west-east direction	m
y	Horizontal coordinate in south-north direction	m
z	Vertical coordinate	m
z_o	Surface roughness length	m
$\delta, \bar{\delta}$	Horizontal divergence	sec^{-1}
$\zeta, \bar{\zeta}$	Vertical component of vorticity	sec^{-1}
θ	Potential temperature $\theta = \frac{T}{P_*}$	Deg K
ρ	Density of air	kg m^{-3}
σ	Static stability $\sigma = \frac{1}{\theta} \frac{\partial\theta}{\partial z}$	m^{-1}
ϕ	Velocity potential	m^2 sec^{-1}
ψ	Stream function	m^2 sec^{-1}
∇	Horizontal vector gradient operator	m^{-1}
∇^2	Horizontal laplacian operator	m^{-2}
Δ	Horizontal grid spacing	m
Δt_ζ	Impulse time for vorticity	sec
Δt_δ	Impulse time for divergence	sec

Fosberg, Michael A., William E. Marlatt, and Lawrence Krupnak. 1976. Estimating airflow patterns over complex terrain. USDA For. Serv. Res. Pap. RM-162, 16 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

A simple one-layer model of atmospheric boundary layer flow was developed for use in complex terrain. The model was derived through simplification of the fundamental Navier-Stokes flow equations.

Although the equations do not describe all flow characteristics, the resultant solution describes a diagnostic model of the vector flow field. It requires much less data than traditional approaches,

The intended primary uses for this model are in providing wind fields for fire behavior prediction and in evaluation of pollution transport patterns.

Keywords: Wind, boundary layer, air pollution, fire weather.

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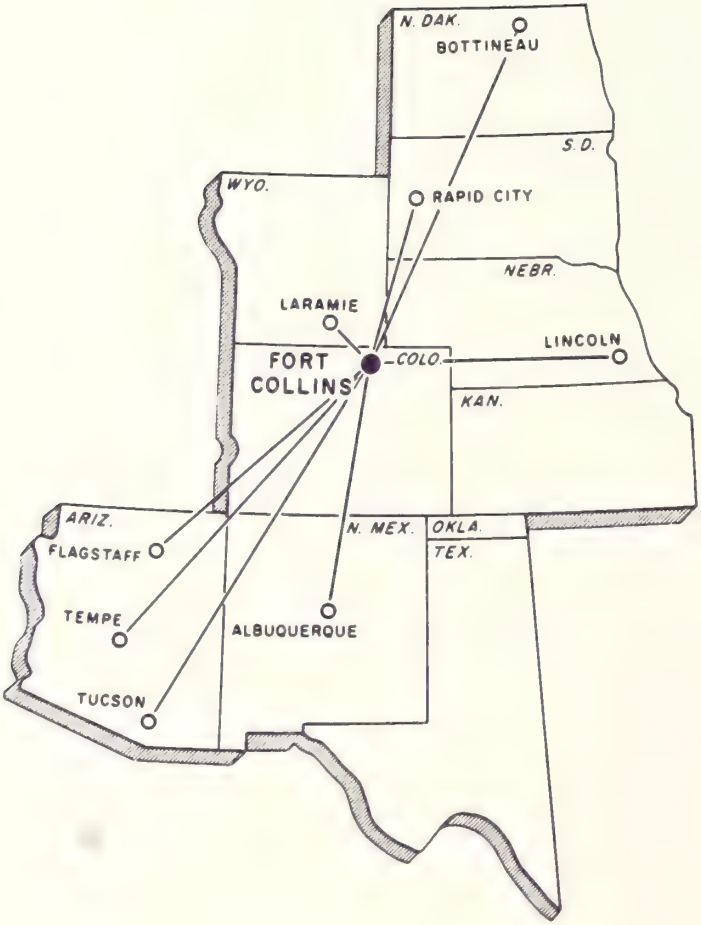
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SWYLD2: Yield Tables for Even-Aged and Two-Storied Stands of Southwestern Ponderosa Pine, Including Effects of Dwarf Mistletoe

by
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Abstract

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Presents a procedure for computation of yield tables for ponderosa pines in Arizona and New Mexico. Possible alternatives include: even-aged or two-storied stands, healthy or diseased stands, and managed or unmanaged stand densities. Stand conditions and severity of dwarf mistletoe infestation change with time and in response to intermediate cuttings. Supersedes SWYLD, published in 1972 as USDA For. Serv. Res. Pap. RM-87. A concise user's guide for program SWYLD2 is available as USDA For. Serv. Gen. Tech. Rep. RM-23, 1976.

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Contents

Page
Introduction 1
Uses of Yield Tables 1
Importance of Dwarf Mistletoe 2
Description of Program SWYLD2 3
Program Relationships 6
User-Supplied Information 9
Local Modifications 14
A Sample Problem 14
Literature Cited 16

Appendices:

1. Listing of Program SWYLD2 17
2. Output of Sample Problem 23

SWYLD2: Yield Tables for Even-Aged and Two-Storied Stands of Southwestern Ponderosa Pine, Including Effects of Dwarf Mistletoe

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Introduction

Computer program SWYLD (Myers and others 1972) was developed to compute yield tables for managed, even-aged stands of southwestern ponderosa pine (*Pinus ponderosa* Laws.). Users of SWYLD recognized a need for a capability of handling a wider range of situations. A few of the original relationships and analytic procedures have been modified and new ones have been added. Program SWYLD2, described in this paper, has been written to supersede SWYLD, published as a USDA Forest Service Research Paper RM-87.

Modifications and additions now provide the following features: (1) yield tables are computed for even-aged stands or for each story of two-storied stands; (2) equations predict the contribution of the overstory to dwarf mistletoe infection in the understory, if any; (3) height and diameter growth equations apply to a wide range of stand densities, and (4) an intermediate or regeneration ut is no longer required at the initial age printed in the yield table.

The material presented includes: (1) descripions of the field measurements, (2) descriptions f the relationships obtained from the measureents, (3) a computer program that contains the elationships, and (4) an example of what the proram can produce. Instructions for adapting the rocedures and program to other species or forest egions are also given.

A published summary of instructions on prepration of yield tables for diseased stands, directed to personnel of pest detection and control rograms, is mostly applicable to SWYLD2 Hawksworth and Myers 1973). One important xception is that the new program is useful for wo-storied stands as well as those that are evenged. A second exception is that SWYLD2 accepts ore than one way of expressing degree of dwarf istletoe infestation.

SWYLD2 is written in standard FORTRAN IV and can be run on almost any computer that provides 50,000 octal memory locations. Yield tables can be produced at a cost of about 8 cents each, excluding cost of program compilation.

Uses of Yield Tables

Yield tables are essential guides for forest managers. They report probable wood yields that result from specified combinations of such factors as site quality, utilization standards, and frequency and intensity of thinning. They are, therefore, the basis for timber management planning. They also provide an important part of the information needed for determining the influence of timber treatments on other forest resources.

Two types of yield tables can be computed by program SWYLD2: (1) tables for managed stands, and (2) tables that describe the remainder of the rotation or life of existing stands. The term "managed," as used in this paper, means stand density is controlled throughout the life of the stand. The term "stand," following the usual definition, refers to an area of trees consistent in site quality, species, structure, density, and incidence of disease. Uniformity of site quality and stand characteristics must be such that site index and other area averages really describe the unit of forest simulated. Stand area, therefore, may range from a very few acres in rough terrain to a hundred or more acres where meaningful averages may be computed.

Managed Stands

Yield tables for managed stands are useful regardless of the current level of management. Well-managed forests can benefit from refinements in operations that are guided by comparisons of actual conditions with a good standard. Where conversion to managed stands is underway, yield tables provide goals toward which conversion can be directed.

Several factors influence the ways that yield tables should be produced and the types of data used to compute them. These factors include:

1. Yield tables for managed stands are needed even for regions and species where managed stands do not yet exist. Temporary plots must be used to obtain needed relationships.
2. No single yield table can be adopted as standard for a species or region. Applied forest management requires the use of various practices that can and will differ from one forest to another, and must appear as variables in yield table computations.
3. A manager should not be restricted to only one yield table per working group, or series of stands managed under the same silvicultural system. He must have the opportunity to examine the probable future results of current operations, to propose changes in the management of resources in his care, and to estimate the effects of these changes before money is spent on them.

The second and third items above relate to a disadvantage of normal and empirical yield tables. One table can report probable yields for only one combination of stand characteristics and management objectives. This is not an effective basis for comparing alternatives and making decisions. Since a group of yield tables can show various combinations of characteristics and objectives, a means of producing many yield tables at low cost can be useful to a forest manager. A computer program that will do this is described below and listed in appendix 1. Once the relationships between stand variables have been established, a manager can examine the probable outcomes of many possible variations in management. There is no need to delay decisions or to speculate on what may happen if a condition or procedure changes.

Existing Stands

Existing stands are mentioned separately from managed stands to emphasize that yield tables have uses besides those for setting management goals. In this case, the question is not the proper management for a specific combination of tree species, region, and objective. Rather, the problem is to select the proper procedure for changing a stand condition that actually exists to some desired condition. Change may be called for because stand density is too high, tree age are greater than planned felling age, or disease problems prevent application of usual management practices.

As an example of the problems created by existing unsatisfactory stand conditions, consider a parasite or other disease on ponderosa pines Management decisions must be made for each diseased stand. Possible alternative treatments are: (1) sanitation thinning, (2) removal of a diseased overstory to release a well-stocked understory, (3) no treatment, with the hope that the stand may eventually become merchantable, or (4) destruction and regeneration. Knowledge of stand structure and density will remove some alternatives from further consideration. For further selection, an estimate of potential yield with each alternative is necessary. This information can be provided by yield tables that describe not managed or goal conditions, but possible results from treating a situation that actually exists. The final alternative chosen must then also consider other forest resources, including scenic values.

Importance of Dwarf Mistletoe

Yield tables for healthy stands do not provide all the information needed for decisionmaking in the Southwest. For practical application, important and predictable causes of reduced growth and yield must be included in the computations. Dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodum* (Engelm.) Hawksw. & Wiens) is so widespread and so reduces growth and yield that it is an important factor in management planning. Andrews and Daniels (1960) found this parasite on 36 percent of some 2,700 ponderosa pine plots located throughout Arizona and New Mexico. On the Lincoln National Forest and adjacent Mescalero Apache Reservation in southern New Mexico, more than 50 percent of the plots were infested (Hawksworth and Lusher 1956, Andrews and Daniels 1960).

Dwarf mistletoe is one of the four major causes of mortality in southwestern ponderosa pine (Pearson 1939, Myers and Martin 1963). Pearson (1938) found mortality in heavily infested, cutover stands to be about five times that in comparable lightly infested or healthy stands. On the Mescalero Apache Reservation, mortality in stands with dwarf mistletoe was nearly twice as high as in healthy stands (Hawksworth and Lusher 1956). The differences were most pronounced in cutover areas, where the mortality rate in infested stands was 3.3 times that in mistletoe-free stands.

Several studies have documented the adverse effects of dwarf mistletoe on the height and diameter growth of individual ponderosa pines (Korstian and Long 1922, Sperry 1934, Hawksworth 1961). Such studies do not, however, reveal the total stand loss due to dwarf mistletoe. They do not report mortality, but give information on surviving trees only.

A recent study compared growth rates and mortality in treated and untreated mistletoe-infested stands in Arizona (Lightle and Hawksworth 1973). Some of the information in SWYLD2 on the effects of dwarf mistletoe was obtained from the plots used for that study.

The publications cited above dealt primarily with the cumulative effects of dwarf mistletoe in unmanaged stands. They do not provide data that can be used directly for yield prediction in managed stands or for comparisons of alternatives. Many of the pine-mistletoe relationships needed for these purposes were reported in the publication describing program SWYLD (Myers and others 1972). Modifications of some of these and additional relationships are reported here for the first time.

The measure of dwarf mistletoe infestation used in SWYLD2 is the 6-class rating system developed by Hawksworth (1961). A rating is obtained for each tree (fig. 1). The individual ratings are then averaged to obtain the value for the entire stand that is used in the relationships of program SWYLD2.

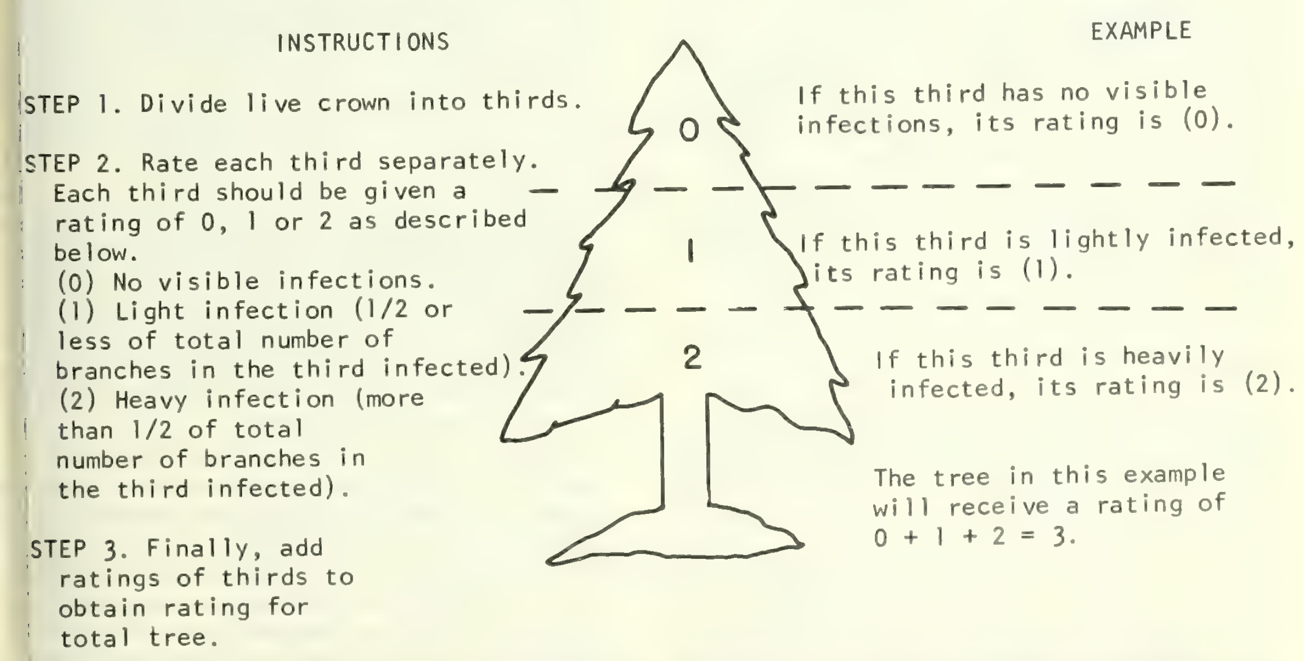
Description of Program SWYLD2

Program SWYLD2 consists of a main program and eight subroutines. Operations performed by each routine are described below and identified by comment statements in the listing of the source program (appendix 1). Subsequent sections of this paper describe the relationships used to compute values of the dependent variables. Input variables and data deck structure are described in the section headed User-Supplied Information.

Main Program

The main program performs the following seven operations:

1. Reads two data cards containing the number of stands to be processed, the length of the projection period in years (10.0 for SWYLD2), and minimum commercial cuts in board and cubic feet.
2. Checks that the number of stands to be processed is not zero or blank. An error message is printed and the entire job terminates if this error is found.
3. Calls subroutine BEGIN at the beginning of processing of each stand to set values of many variables to zero and to read all data applicable to the stand being processed.



INSTRUCTIONS

STEP 1. Divide live crown into thirds.

STEP 2. Rate each third separately. Each third should be given a rating of 0, 1 or 2 as described below.
(0) No visible infections.
(1) Light infection (1/2 or less of total number of branches in the third infected).
(2) Heavy infection (more than 1/2 of total number of branches in the third infected).

STEP 3. Finally, add ratings of thirds to obtain rating for total tree.

EXAMPLE

If this third has no visible infections, its rating is (0).

If this third is lightly infected, its rating is (1).

If this third is heavily infected, its rating is (2).

The tree in this example will receive a rating of 0 + 1 + 2 = 3.

Figure 1.—Instructions for and example of the use of the 6-class mistletoe rating system (Hawksworth 1961).

4. Checks many variables of the data deck for unwanted zero or blank values. An error message is printed and processing terminates for any stand with such errors in the data cards. Understory variables are not checked because they must have zero or blank values for single-storied stands.

5. Calls subroutine FIRST to compute initial values of several stand characteristics and program controls.

6. Calls 2 subroutines (CUTS, PROJ) in sequence as many times as necessary to simulate the number of projection periods required to reach the final age desired for each yield table.

7. Calls subroutine TABLE after each stand is processed to print yield tables for the stand. One table is produced for single-storied stands. Separate tables are printed for the overstory and understory of two-storied stands.

Subroutine BEGIN

Subroutine BEGIN is called by the main program to initiate the processing of each set of stand data. Many variables are assigned initial values of zero to clear computer memory of data from previous computations, and to prevent processing of an understory in single-storied stands. Four cards (types 3, 4, 5, and 6) are read by BEGIN to describe stand conditions and the management controls to be used in computations. These stand and control variables are described in a subsequent section and in the listing of the Order and Contents of the Data Deck.

Values of 21 input variables are stored in an array named VAR. Some items in VAR are examined by the main program to locate errors, as already described. Others are used by other subroutines as a record of initial values.

The data deck for one job must contain one set of four cards (types 3, 4, 5, and 6) for each stand to be processed. The number of sets or stands is specified by a value read by the main program.

Subroutine FIRST

FIRST computes values of several variables that, with the input variables, describe the stand and the management decisions applicable to it. Where appropriate, separate values are computed for each story of two-storied stands. The final age to appear in the yield table and the initial basal area are computed. Initial dwarf mistletoe rating and average heights of dominant and codominant trees are also computed if these values have not been entered for the stand.

Subroutine SWVOL is called by FIRST t compute initial stand volume per acre in each o the units provided for in SWVOL. These volume plus other computed values are then stored fo later recall when the yield tables are printed.

Subroutine CUTS

CUTS executes the thinnings and regeneration cuts called for by the variables specifying management controls. CUTS also makes any necessary changes in the interval between cut and in residual density of shelterwoods.

A scheduled thinning will be bypassed if any one of the three following conditions exists at the time the thinning should occur:

1. Comparison of current growing stock leve with the growing stock goal indicates that the stand or story is already understocked in relation to the goal.

2. Current dwarf mistletoe rating exceeds the maximum value specified by the program user This value will usually be 3.0 for the host-parasite combination of SWYLD2.

3. Noncommercial volumes would be cut and the appropriate control variable is given a value to deny this option.

Each partial cut executed is followed by computation of new values for each average stand d.b.h., average stand height, and dwarf mistletoe rating. Each new diameter and height is larger or smaller than the corresponding old value, depending on the type of cutting executed. Post-cutting basal areas, residual volumes, and volumes removed are also computed and stored for later printing in the yield tables.

In two-storied stands, CUTS executes thinnings and regeneration cuts separately for each story. The user may specify simultaneous cuttings in both the overstory and understory or a cutting in only one story. Growing stock level specified for a cut applies only to the basal area and average diameter of the story involved and not to the combined basal area of both stories.

The first thinning in diseased stands will be from above, as simulated by subroutine SWCUT2, unless the option of preventing thinning from above is exercised. Average diameters and heights will therefore be reduced. Subsequent thinnings in diseased stands will increase average d.b.h. and height, but by lesser amounts than in healthy stands, where the smaller trees make up a larger percentage of those removed. This effect, an alternative computation in SWCUT1, has been observed in subsequent thinnings of actual diseased stands.

Subroutine PROJ

Subroutine PROJ contains the relationships of SWYLD2 that describe growth and other changes over time. The routine consists of one long loop to process the values of each story of two-storied stands separately.

Values computed by PROJ during each projection period, if needed, are as follows: (1) nonzero dwarf mistletoe rating (DMR) that accounts for latent infestation after apparent elimination of the parasite by partial cutting, (2) initial DMR if infestation occurs after the simulation period begins, (3) value of DMR at the end of the period if an infestation exists and if neither of the previous situations apply, (4) actual growing stock level, (5) average d.b.h. and height at end of the period, and (6) mortality during the period. Computations of d.b.h., height, and mortality include the effects of dwarf mistletoe, if present. PROJ uses the combined basal area of both stories (SBAS) in calculations of growing stock level for each story, growth projections, and mortality calculations.

PROJ completes the operations of each projection period by calling SWVOL to compute volumes. These and other values are then stored for printing at the end of the simulation.

Subroutine TABLE

TABLE is called by the main program after each set of stand data is processed. In two-storied stands, yield tables for the overstory and understory are printed separately and labeled to identify the stand component described. Only one table, without a story designation, is printed for single-storied stands. Examples of the tables are given in appendix 2.

Footnotes to each table report: (1) merchantability limits for cubic- and board-foot volumes, (2) type of initial thinning allowed, (3) minimum DMR that prevents intermediate cuts, (4) minimum volumes included in total yields, (5) controls on noncommercial thinnings, (6) initial status of dwarf mistletoe infestation if DMR is not read from data card type 5, and (7) skipping of scheduled intermediate cuts.

Subroutine SWVOL

Subroutine SWVOL is called by other subroutines after each growth projection and after each intermediate or regeneration cut. Total cubic volume per acre (TCF) of all trees, from groundline to tip, is computed with stand volume equations. Factors are then computed and used to convert total cubic volumes to merchantable cubic feet (FCTR) and to board feet (PROD). Utilization standards for these units are given in the comment statements of SWVOL and in footnotes to the yield tables.

Two or three equations each are used to compute TCF, FCTR, and PROD to avoid the need for complex forms. These relationships are not linear over the necessary ranges of the independent variables.

Conversions to other units or utilization standards may supplement or replace those already in SWVOL (appendix 1). Additional units might be square feet of veneer or wood weight in pounds (Myers 1960).

Subroutine SWCUT1

Subroutine SWCUT1 computes average stand d.b.h. after partial cuttings that emphasize, but are not restricted to, removal of the smaller trees. Average diameter and height after cutting, therefore, are larger than corresponding values before cutting. The percentage of trees retained is needed as an independent variable, but is itself an unknown. Successive percentages of trees are therefore tested until d.b.h. after cutting, number of trees retained, and residual basal area agree with the growing stock level selected by the program user.

Two major loops in the subroutine provide for the increasing and constant segments of each growing stock level curve (fig. 2). Limiting d.b.h. for selection of loops is 10.0 inches minus the average change expected with light partial cuttings in stands just under 10.0 inches d.b.h.

Computed increases in average d.b.h. of diseased stands are half the increases of similar, healthy stands, as occurs in actual dwarf mistletoe-infested stands, because more of the larger trees are removed than would otherwise be the case.

Subroutine SWCUT2

SWCUT2 computes the reduced average d.b.h. that results when thinning from above in dwarf mistletoe-infested stands. The computations, Equations for post-thinning diameters are derived from data obtained in a variety of stands marked for thinning. Thinnings simulated on a computer also provide data for the equations (Myers 1971).

4. Height Increase from Growth

Equations in subroutines FIRST and PROJ compute average heights of dominant and codominant trees in healthy stands. Equations for HTSO and TEMH apply to stands of basal area less than or within the range of possible management goals. The equation for HTNEW applies to stands of greater density. The equations for HTSO in FIRST are bypassed if actual initial heights are read in.

Two equations for reduction in height growth due to dwarf mistletoe are based on data from infested stands. The equation for HTPCT in FIRST computes any reduction during the period from stand origin to AGEO and is not used if initial heights are read in. The equation for PCT in PROJ provides the reduction for a single projection period. Procedures for measurement and regression analysis of field data parallel those for the diameter growth equations described above.

Stand ages used in the equations are averages of dominant and codominant trees. For a two-storied stand, age of the understory is obtained from trees judged to be potential dominants and codominants.

5. Height Change from Thinning

Two equations for ADDHT in subroutine CUTS compute the change in average height due to partial cutting. One equation determines the increase resulting from thinning primarily from below. The other estimates the decrease in average height that occurs when cutting from above with emphasis on removal of the larger trees. At each cutting, the current value of ADDHT is added algebraically to height before thinning to obtain average height after thinning. Computed values of ADDHT are small when thinning from below because average heights and their changes refer to dominant and codominant trees only.

6. Noncatastrophic Mortality

Equations to estimate mortality in healthy (OUT) and diseased (DIE) stands require values for several easily measured stand variables. Data for regression analyses came from permanent and temporary plots, with and without dwarf mistletoe. As used here, the term "noncatastrophic refers to gradual losses from competition, endemi insect populations, and dwarf mistletoe. Effect of forest fires, insect epidemics, and other abrup changes are not computed by these equations.

Reduction in numbers of trees is importan in unthinned stands of ponderosa pine, but is minor and erratic in healthy, thinned stands. A prediction equation for mortality could not be computed for healthy thinned stands with an average d.b.h. of 10.0 inches or larger. Subroutine PROJ therefore computes mortality reductions only for mistletoe-free stands that average less than 10.0 inches d.b.h. Losses are computed for all infested stands with a DMR large enough to influence rate of mortality. In all computations mortality is a percentage expressed as a decimal.

7. Dwarf Mistletoe Infestation

Several prediction equations compute initial dwarf mistletoe ratings (DMR) and subsequent annual or periodic increases. Data used to obtain these equations come from permanent and temporary plots. Three ways of reporting initial degree of infestation are provided. One alternative is to enter DMR as part of the input. Otherwise, stand age at time of initial infestation or the percentage of trees infected may be used.

Initial ratings are computed by subroutines FIRST or PROJ, if an initial DMR is not reported. The first equation for an initial rating computes DMR from the percentage of infected trees (PINF) in the story or even-aged stand. This requires that PINF be read in as a second alternative way of reporting the degree of infestation. Methods for determining PINF in southwestern ponderosa pine stands were described by Walters (1975). The other three computations of initial DMR are based on another alternative, use of the variable START. This is the average tree age when the story or even-aged stand is first infected. It is the mean age when infection began at various points throughout the story or stand. It is not the age when earliest infection occurred. Three equations involving TIME (derived from START) are needed, one for an overstory or single-storied stand, one for understories with less than 3,000 trees per acre, and another for understories of greater density.

A value of PINF is computed in CUTS, even when other alternative measures of degree of infestation have been provided. This value for PINF is then used to compute the buildup of infestation over a 20-year period after DMR has apparently been reduced to zero by partial cutting.

Values of DMR computed from START and TIME apply to infested stands that have never been partially cut. To simulate future growth in actual stands that have been partially cut, either DMR or PINF should be used to describe the infestation.

Four equations for YDM in subroutine PROJ provide the annual increase in dwarf mistletoe rating that is then used to obtain the new rating at the end of the projection period. The first equation for YDM applies to the increase in even-aged stands or to overstories. The third and fourth equations apply to understories and include the additional contribution of dwarf mistletoe seeds from the overstory. The second equation, YDM = 0.08, provides the constant increase in stands of 15 or less trees per acre. Spread of infection in such open stands is within-tree and not between trees.

The two equations for DMR in PROJ that use computed values of YDM contain no species-specific regression coefficients. The weights of 0.5 and 1.0 assigned the periodic increases may, however, be different for other combinations of host and parasite.

8. Decrease in DMR from Thinning

Two equations in CUTS compute the reduction in dwarf mistletoe rating produced by partial cutting. An initial cut in an infested stand will emphasize removal of the larger trees unless the option is overridden by a non-zero value of IOPT on data card type 4. The equation for DELDMR computes the reduction if the initial thinning is from above. The next statement in the subroutine applies to thinnings from below, and indicates that the reduction in DMR is ⅔ of that possible when thinning from above.

The equations were computed from data obtained by simulation of thinnings in actual stands.

Thinnings are not performed if the current DMR exceeds the value of DMLEV read in by data card type 4. A DMLEV value of 3.0 is usually appropriate for the host-parasite combination described here.

9. Stand Volume Equation

Volumes per acre in total cubic feet inside bark from groundline to tip (TCF) are computed from stand volume equations. Tree volume equations for southwestern ponderosa pine (Myers 1963) were used to obtain plot volumes for the regression analysis. Two statements for TCF appear in subroutine SWVOL because the relationship is not linear over the range of D^2H that can appear in yield tables.

Total cubic feet is the only volume computed directly by SWYLD2. Volumes in other units are obtained from total cubic volume and appropriate conversion factors, as explained below.

10. Volume Conversion Factors

Volumes in total cubic feet can be converted to merchantable cubic feet, board feet, square feet of veneer, weight per acre, or other units. Appropriate factors are used to make conversions. Subroutine SWVOL converts total cubic volumes to merchantable cubic feet (with FCTR) and to board feet Scribner Rule (with PROD). Footnotes to the yield tables give minimum limits for tree d.b.h. and top diameter.

Plot data used to compute total cubic feet also provide volumes in other units of interest (Myers 1963). The quantity of each unit per total cubic foot is determined separately for each plot. These ratios are then used to obtain equations for FCTR and PROD. Three equations for FCTR and two for PROD are included in SWVOL to simplify regression analysis.

Ratios are not computed for the smallest average stand diameters because the factors vary greatly in such stands. This variation has no important effect on yield table construction. Merchantable material will not be a part of thinnings until stand diameter is large enough for conversion factors to be reliable.

User-Supplied Information

Values of 38 variables that describe stand conditions or control program execution are read from data cards supplied by the program user. Twelve of these values must be zero or blank, if the data apply to an even-aged stand. Names, input formats, sequence for punching, and definitions of these variables are given in the tabulation headed Order and Contents of the Data Deck. Twenty variables that require management decisions or the collection of field data are described in detail in this section.

1. Initial Stand Measurements

Values for AGEO, DBHO, HTSO, and DENO on data card type 5 are obtained in one of two

Order and Contents of the Data Deck

Card type	Number of cards	Variable name	Columns	Format	Description of variable
1	1	NSTND	1-5	I5	Number of stand records to be processed in a single job.
		RINT	6-10	F5.0	Number of years for which growth and infection equations make one projection of growth or change. Value is 10.0 for the equations in appendix 1.
2	1	COMCU	1-5	F5.0	Minimum cut in merchantable cubic feet to be included in total yields. Must be at least 1.0.
		COMBF	6-10	F5.0	Minimum cut in board feet to be included in total yields. Must be at least 1.0.
3	1 per stand	NOTE(I)	1-80	16A5	Description of test conditions for the stand being processed.
4	1 per stand	ICUT	1-5	I5	Control to choose: no precommercial thinnings (0), initial precommercial thinning only (1), no restriction on precommercial thinnings (2).
		DMLEV	6-10	F5.1	Dwarf mistletoe rating above which no intermediate cutting will be done.
		DELAY(1)	11-15	F5.0	Number of years between initial age in yield table and tree age at first cut in the overstory.
		IOPT(1)	16-20	I5	Initial thinning in diseased overstory to be from above (0) or below (1).
		THIN(1)	21-25	F5.0	Growing stock level for initial thinning in a healthy overstory.
		DSTY(1)	26-30	F5.0	Growing stock level for intermediate cuts after the first in the overstory.
		JCYCL(1)	31-35	I5	Interval between intermediate cuts in the overstory.
		DELAY(2)	36-40	F5.0	Number of years between initial age in yield table and tree age at first cut in the understory.
		IOPT(2)	41-45	I5	Initial thinning in diseased understory to be from above (0) or below (1).
		THIN(2)	46-50	F5.0	Growing stock level for initial thinning in a healthy understory.
		DSTY(2)	51-55	F5.0	Growing stock level for intermediate cuts after the first in the understory.
		JCYCL(2)	56-60	I5	Interval between intermediate cuts in the understory.
5	1 per stand	STND	1-5	F5.0	Number of the stand.
		SITE	6-10	F5.0	Site index of the stand.
		AGEO(1)	11-15	F5.0	Age of overstory at first entry in the yield table.
		DBHO(1)	16-20	F5.1	Average d.b.h. of the overstory at age AGEO(1).
		HTSO(1)	21-25	F5.1	Average height of overstory dominants and codominants at age AGEO(1).
		DENO(1)	26-30	F5.0	Number of live trees per acre in the overstory at age AGEO(1).
		DMR(1)	31-35	F5.1	Average dwarf mistletoe rating of overstory at age AGEO(1).

		PINF(1)	36-40	F5.1	Percentage of overstory trees infected by dwarf mistletoe at age AGEO(1).
		START(1)	41-45	F5.0	Age of overstory when dwarf mistletoe infection begins. Enter number larger than largest REGN if infection will not occur during the rotation.
		AGEO(2)	46-50	F5.0	Age of understory at first entry in the yield table.
		DBHO(2)	51-55	F5.1	Average d.b.h. of the understory at age AGEO(2).
		HTSO(2)	56-60	F5.1	Average height of potential dominants and codominants in understory at age AGEO(2).
		DENO(2)	61-65	F5.0	Number of live trees per acre in the understory at age AGEO(2).
		DMR(2)	66-70	F5.1	Average dwarf mistletoe rating of understory at age AGEO(2).
		PINF(2)	71-75	F5.1	Percentage of understory trees infected by dwarf mistletoe at age AGEO(2).
		START(2)	76-80	F5.0	Age of understory when dwarf mistletoe infection begins. Enter number larger than largest REGN if infection will not occur during the rotation.
6	1 per stand	REGN(1)	1-5	F5.0	Stand age when first regeneration cut will occur. Must never be zero or blank. This is age for clearcutting if rest of card is zero or blank.
		VLLV(1)	6-10	F5.3	Percentage of DSTY to be left at age REGN(1). Will be zero with clearcutting. Enter as a decimal.
		REGN(2)	11-15	F5.0	Stand age at which second regeneration cut, if any, will occur. Age for removal of seed trees or second cut of shelterwood.
		VLLV(2)	16-20	F5.3	Percentage of basal area left after first regeneration cut to be left at age REGN(2). Will be zero except for 3-cut shelterwood. Enter as a decimal.
		REGN(3)	21-25	F5.0	Stand age at which third regeneration cut, if any, will occur. Final cut of 3-cut shelterwood.

ways, depending on the purpose of the computer run. These stand descriptors are printed on the first line of the yield table; thus they report initial conditions. Ways of obtaining the data are:

a. When the purpose is to estimate performance of a future or hypothetical managed stand: examine numerous young stands to determine the average d.b.h. and height attained at various ages for each site class and for each of several stand densities. The objective is to describe stand conditions at some selected age (AGEO) if regeneration and subsequent growth and mortality progress according to some goal set for the site class and density.

b. When the purpose is to estimate future performance of an actual stand: obtain age, average d.b.h., average dominant and codominant height, and number of trees per acre by usual stand inventory procedures.

AGEO is the average age of living dominant and codominant trees. For an understory, age of potential dominants and codominants is determined separately from age of the overstory. AGEO is the first age that will appear in the yield table for each stand and, unless a delay is called for, will be stand age at time of the first cutting computed by SWYLD2. AGEO for actual stands is age at time of inventory. In the case of hypothetical stands examined to establish management principles, AGEO should usually be age at time of first thinning.

DBHO is average d.b.h. of all live trees at age AGEO, regardless of crown class. For two-storied stands, DBHO is determined separately for each story. DBHO should be determined to the nearest 0.1 inch. Average d.b.h. is the diameter of the tree of average basal area.

HTSO is the average height of live dominant and codominant trees of an even-aged stand, or of a single story of a two-storied stand. As with AGEO, an understory value is obtained from trees judged to be potential dominants and codominants. HTSO may be omitted from data card type 5 if a hypothetical stand with a density below growing stock level 160 is being examined. Values for HTSO are computed if zero or blank fields appear on the data cards. For actual stands, measured heights should be used to account for the past effects on height growth of stand density and disease.

DENO is the number of live trees per acre in an even-aged stand or in each story of two-storied stands. All trees over 4.5 feet tall are counted, regardless of crown class. These are the same trees used to obtain DBHO.

2. Initial Dwarf Mistletoe Conditions

Three situations involving time of initial infestation can be examined for actual or hypothetical stories or stands. For each, a non-zero value of one variable is punched in data card 5 and the values of the other two disease variables are zero or blank. The situations are:

1. The story or stand is already infested at age AGEO, the first age in the yield table. Either the DMR or the percentage of trees infected is known.
2. Infestation begins at any time before or during the period simulated, and story or stand age at this time is known.
3. The story or stand remains healthy throughout the period simulated.

An infestation already present at age AGEO is described in either of two ways:

1. DMR—average dwarf mistletoe rating (see fig. 1) at age AGEO of all trees of an actual story or stand or a selected value assigned to a hypothetical stand. A non-zero value of DMR on the data card causes statements that compute initial DMR to be bypassed.
2. PINF—percentage of the live trees infected with dwarf mistletoe in an actual or hypothetical story or stand at age AGEO. DMR is later computed from PINF.

An infestation that begins at a known stand or story age, before or after AGEO, is described by the variable START. This is the average age of the dominant and codominant trees when the story or stand is first infected. Refer to item 7 of "Program Relationships" for a detailed definition of START. Preferably, START should be used only when simulating growth in hypothetical stands. DMR is computed from START only if both the DMR and PINF fields of data card type 5 are zero or blank.

All computations of DMR must be bypassed if the story or stand remains mistletoe-free throughout the period simulated. This is done by entering zero values for both DMR and PINF and a value for START greater than the largest value of the three REGN variables. For example, if with 2-cut shelterwood REGN(1) equals 110, REGN(2) equals 130, and REGN(3) equals 0, then START must have some value greater than 130.

3. Site Index

The site index value read in for each stand is based on mean height of dominant and codominant trees at a base age of 100 years. Tables and graphs published by Meyer (1938) provide the relationships used to determine each index.

Site index values used in growth computations for actual stands must be reliable indicators of relative productivity. Trees in dense stands or with any disease or deformity severe enough to reduce height growth do not furnish reliable information. In such cases, site index can be obtained from suitable nearby stands or from soil variables.

4. Intermediate Cuts

Seven variables on data card type 4 control the execution of intermediate cuts. Eleven fields are provided for them, since four variables require separate entries for each story of two-storied stands. The purpose of each variable is as follows:

1. ICUT—control of the number of noncommercial thinnings that will be simulated. An input value of zero causes all noncommercial thinnings to be bypassed. Assign ICUT a value of one if only the initial thinning can be noncommercial. An input value of two results in all scheduled

thinnings being performed, regardless of how many may be noncommercial. Minimum volumes for commercial cuts are entered as COMBF and COMCU on data card type 2. Variables COMBF and COMCU must be assigned values of at least 1.0, regardless of the value of ICUT.

2. **THIN**—growing stock level for initial thinning in healthy stands. Levels are designated in the manner shown in figure 2. They will frequently be 80, 90, or 100 for southwestern ponderosa pine, but may range from 40 to 160.

3. **DMLEV**—maximum dwarf mistletoe rating above which intermediate cuttings will not be performed. A value of 3.0 will often be used for ponderosa pine. Experience indicates that thinnings cannot materially reduce effects of the infestation or improve stand growth when DMR exceeds 3.0.

4. **JCYCL**—interval between intermediate cuts, as punched on card type 4. JCYCL is later redefined in subroutine CUTS when an interval between regeneration cuts is needed. Values assigned to JCYCL must be a multiple of the projection period of the growth and mortality equations (RINT). For example, the equations of SWYLD2 project d.b.h. and other measures for 10-year periods, and RINT has a value of 10.0. The value of JCYCL on card type 4 can therefore be 10, 20, 30, etc. years.

5. **DSTY**—growing stock level for intermediate cuts after the first cut. Discussion of choice of level for THIN, above, also applies to DSTY. Levels assigned to THIN and DSTY may be equal.

6. **DELAY**—number of years between the first age reported in the yield table (AGEO) and age of the story or stand at time of the first simulated cutting. The value of DELAY must be a multiple of the value of RINT. The variable DELAY schedules the first cut but does not assure that it actually will be performed. Restriction on noncommercial thinning, basal area less than the growing stock goal, or a value of DMR larger than DMLEV will prevent or postpone thinning regardless of the value of DELAY. nitial cutting will take place at age AGEO if DELAY is assigned a value of zero and if other estrictions on cutting do not apply.

7. **IOPT**—control on whether or not the initial thinning in an infested stand will be from above. Thinning from above emphasizes, but is not restricted to, removal of the larger trees. Such cutting is usual practice in infested stands because the larger trees usually support the greater amounts of dwarf mistletoe. IOPT is assigned a value of zero if initial thinning is to be from above and a value greater than zero if the initial thinning is to be from below. Regardless of the value of IOPT, thinning will not be performed unless all restrictions on thinning are met.

5. Regeneration Cuts

Entries on data card type 6 determine the method of regeneration to be simulated, stand age when each cut will be performed, and the basal area to be left for seed trees or shelterwood. Stand ages at regeneration cuts must equal the sum of AGEO plus appropriate multiples of the value of RINT. Regardless of regeneration method, REGN(1) will never be assigned a value of zero on data card type 6.

For clearcutting, stand age at time of final cutting, or REGN(1), is the only entry needed on the card.

Seed tree cutting requires that values for REGN(1), VLLV(1), and REGN(2) be punched in card type 6. REGN(1) is the stand age at first regeneration cutting, and REGN(2) is stand age when the seed trees are removed. The interval between AGEO and REGN(1) and the interval between REGN(1) and REGN(2) must each be a multiple of RINT. VLLV(1) is the percentage of the growing stock goal, DSTY, to be left for seed trees. VLLV(1) is entered as a decimal.

Shelterwood cuttings are controlled in the same manner as seed tree cuts except that up to three regeneration cuts are possible. The restrictions on formats and intervals described above also apply here. Two-cut shelterwood requires that values be assigned to the same three variables used with the seed tree method, described above. For three-cut shelterwood, REGN(1) and REGN(2) are stand ages at the two removal cuts and REGN(3) is stand age at the final cut. VLLV(2) is the percentage of the shelterwood basal area left at age REGN(1) that will be retained at age REGN(2). For example, assume that DSTY is 100 square feet and that VLLV(1) and VLLV(2) are 0.5 and 0.4, respectively. Basal area of the shelterwood at age REGN(1) will be 50 square feet. Residual basal area at age REGN(2) will be 20 square feet.

Local Modifications

This section may be skipped by readers who are not modifying SWYLD2 for local use. If the adaptation is to apply to healthy, single-storied stands only, it will be more efficient to modify program PONYLD (Myers 1971) rather than SWYLD2.

Complete modification of SWYLD2 for other host-dwarf mistletoe combinations, regions, thinning specifications, and utilization standards requires replacement of 65 statements that compute values of 24 variables. The statements are described in the section headed "Program Relationships." The 65 replacements require that coefficients for 46 different relationships be computed. The difference of 19 is due to duplication among the 65 replaceable statements. The 46 different relationships include several cases where, for simplicity of regression analysis, a single variable is computed by two or three separate relationships.

The 65 replaceable statements described below do not include the IF statements needed to select one appropriate statement from among the two or three provided for some variables. The number of IF statements to be modified or removed will depend on the results of each regression analysis.

Statements to be replaced for complete modification are in six subroutines, as follows:

FIRST has seven replaceable statements: four for DMR, two for HTSO, and one for HTPCT.

CUTS has eight replaceable statements: three for GSLEVL, two for DELDMR, two for ADDHT, and one for PINF.

PROJ has 23 replaceable statements:

Variable	Statements	Variable	Statements
DMR	6	DIE	1
DENT	1	OUT	1
YDM	4	TEMH	2
GSLEVL	3	HTNEW	1
DBHO	2	PCT	1
DINC	1		

The first four statements for DMR contain the same coefficients as the four in subroutine FIRST. The last two statements for DMR have weighting factors of 0.5 and 1.0 that could vary by species. The IF statement using DENT, immediately following the statement labeled 20, contains a constant that may be species-specific. Three statements for YDM resemble three of the statements for DMR, but do not include the variable TIME. The other statement for YDM sets a constant value of 0.08 that may be species-specific. Statements for GSLEVL are the same in PROJ and CUTS. Two statements for TEMH have the same coefficients as the statements for HTSO in subroutine FIRST. The remaining seven replaceable statements in PROJ are not duplicated in PROJ or in other subroutines.

SWVOL has seven replaceable statements: two for TCF, three for FCTR, and two for PROD. None of them are duplicated elsewhere in the program.

SWCUT1 has 14 replaceable statements, none of which are duplicated elsewhere. Long statements for DBHE and PDBHE (log-log relationship for DBHE) each appear twice. Two short identical statements for DBHE just before the statements labeled 20 and 70, contain a constant 0.5 that may be species-specific. With other host–parasite combinations, thinning from below in diseased stands may not produce half the change in d.b.h. that thinning from below produces in healthy stands. The remaining eight replaceable statements are not duplicated in SWCUT1 or elsewhere. They include one statement each for BREAK and BUST, three statements for SQFT, and three statements for DBHP.

SWCUT2 has six replaceable statements, four of which are duplicated elsewhere. The three equations for GSLEVL have the same coefficients as those in CUTS and PROJ. The equation for DBHE just before the statement labeled 30 also appears in SWCUT1. The two long statements for DBHE (one as PDBHE for a log-log relationship) compute the reduced d.b.h. after thinning from above, and do not appear elsewhere.

Seventeen statements relating to stocking need not be replaced if the method of expressing stocking levels shown in table 1 and figure 2 is retained. These 17 include nine statements for GSLEVL in CUTS, SWCUT2, and PROJ. Other retainable statements are in SWCUT1: three for DBHP, one each for BREAK and BUST, and three for SQFT.

Several statements in subroutine TABLE that write table headings and footnotes must be modified to conform to changes in species, units of measure, or utilization standards.

A Sample Problem

The problem described below demonstrates most of the computations made by SWYLD2 and the printed results obtained. It illustrates some of the questions that may be asked and the information that will be provided. For brevity, only three of the many possible stand conditions are examined. The example also serves as a test problem for use in adapting the source program to locally available computing facilities.

Assume a forest composed of even-aged and two-storied stands of ponderosa pine with differing degrees of infestation by dwarf mistletoe. Some of the many questions the manager of such a forest would have and their relation to management include:

1. What growth can be expected in a hypothetical even-aged stand, without dwarf mistletoe, that is to be managed according to a selected set of management controls? Initially, many yield tables would be produced to examine the effect of variations in length of cutting cycle and other controls on yields and on the number of precommercial thinnings required.
2. How would this performance be affected by a dwarf mistletoe infestation that started when the stand was 10 years old? Tables of this type provide information on impacts of the disease, free of the accidents of past history of actual stands.
3. What yields can be expected from an existing two-storied stand infested with dwarf mistletoe if the overstory is removed now? This and the next question relate to determination of the best way of converting an undesirable stand condition to something better.
4. What would be the effect on yield if question 3 were modified to delay overstory removal for 20 years?

For purposes of this example, assume that the values of several management controls have been standardized for the working circle. Cutting cycle length is 20 years. Initial thinnings in young stands reduce density to growing stock level 120. Other intermediate cuts are to growing stock level 90. Only the first thinning may be noncommercial. Minimum commercial volumes per acre are 320 cubic feet to a 4-inch top and 1,500 board feet. Regeneration is by two-cut shelterwood with a removal cut at stand age 110 and the final cut at age 130. The manager expects that his procedure for regeneration cuts will result in a new stand with 950 trees per acre at age 30. This new crop will average 4.8 inches in diameter on areas of site index 70.

The data deck consists of the 18 cards shown in figure 3. The first two cards shown are the type 1 and type 2 cards, respectively, read by the main program. The next four cards are the type 3, 4, 5, and 6 cards used to answer the first of the questions listed above. The remaining 12 cards are the type 3, 4, 5, and 6 cards for the other three questions.

Yield tables produced by SWYLD2 to answer the four questions given, and with the data deck described above, are reproduced in appendix 2.

Yield tables can be used in many ways to assist in decisionmaking. For many purposes, yields of healthy stands will be desired so that

```
                                          COLUMN NUMBERS

                   1         2         3         4         5         6         7         8
          12345678901234567890123456789012345678901234567890123456789012345678901234567890

CRD TYPE

   1          4   10

   2        320 1500

   3      HYPOTHETICAL HEALTHY EVEN-AGED STAND. BEGIN TABLE AT AGE 30.
   4          1   30    0    0  120   90   20    0    0    0    0    0
   5          1   70   30   48    0  950    0    0  999    0    0    0    0    0    0    0
   6        110  500  130    0    0

   3      HYPOTHETICAL EVEN-AGED STAND. INFESTATION STARTS AT AGE 10.
   4          1   30    0    0  120   90   20    0    0    0    0    0
   5          2   70   30   48    0  950    0    0   10    0    0    0    0    0    0    0
   6        110  500  130    0    0

   3      TWO-STORIED INFESTED STAND WITH IMMEDIATE OVERSTORY REMOVAL.
   4          1   30    0    0  120   90   20    0    0  120   90   20
   5          3   70  150  161  750   20   48    0    0   30   41  210  600   10    0    0
   6        110  500  130    0    0

   3      TWO-STORIED INFESTED STAND. OVERSTORY REMOVAL DELAYED 20 YEARS.
   4          1   30   20    0  120   90   20   20    0  120   90   20
   5          4   70  150  161  750   20   48    0    0   30   41  210  600   10    0    0
   6        110  500  130    0    0
```

Figure 3.—Data deck for sample problem.

long-range goals can be determined. Yields, number of noncommercial cuts, number of scheduled cuts that cannot be made, and size of the average tree are some of the values produced. Money yields and rates earned can be computed if necessary data on costs and stumpage values are available. Stand ages at culmination of mean annual increment, and rates earned can help the manager determine suitable rotations for his working groups.

With a disease as important as dwarf mistletoe, it is also necessary to project the growth of diseased stands. Two important types of information can be obtained from yield tables that include disease effects. A comparison of projected yields of healthy and diseased stands indicates the impact of the disease on the timber resource. Yield tables for actual diseased stands indicate the types of treatment that may be practical, and give an estimate of the expected benefits.

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APPENDIX 1
Listing of Program SWYLD2

```
      PROGRAM SWYLD2
     1(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C TO COMPUTE AND PRINT YIELD TABLES FOR EVEN-AGED AND TWO-STORIED STANDS
C OF SOUTHWESTERN PONDEROSA PINE WITH OR WITHOUT DWARF MISTLETOE.
C
C DEFINITIONS OF VARIABLES.
C     SUBSCRIPTS -
C     I = 1 FOR OVERSTORY, I = 2 FOR UNDERSTORY.
C     J = 1, 2, OR 3 TO NUMBER REGENERATION CUT.
C     K = AGE CLASS AT TIME OF OPERATION.
C
C     ADDHT(I) = INCREASE OR DECREASE IN AVERAGE STAND HEIGHT FROM
C          PARTIAL CUTTING.
C     AGEO(I) = INITIAL AND SUBSEQUENT AGES IN YIELD TABLE.
C     BASO(I) = BASAL AREA PER ACRE BEFORE PARTIAL CUTTING.
C     BAST(I) = BASAL AREA PER ACRE AFTER PARITAL CUTTING.
C     BREAK = POINT WHERE GROWING STOCK RELATIONSHIP OF DIAMETER ON
C          BASAL AREA IS BROKEN INTO SEGMENTS.
C     BUST = POINT WHERE GROWING STOCK RELATIONSHIP OF DIAMETER ON
C          BASAL AREA IS BROKEN INTO SEGMENTS.
C     CBAS(I,K) = BASAL AREA REMOVED.
C     CBF(I,K) = M BD. FT. REMOVED.
C     CDEN(I,K) = NUMBER OF TREES REMOVED.
C     CHNG = PERIODIC INCREASE IN AVERAGE DOM AND CODOM HEIGHT.
C     CMCF(I,K) = MERCH. CU. FT. REMOVED.
C     COMBF = MINIMUM COMMERCIAL CUT, BOARD FEET.
C     COMCU = MINIMUM COMMERCIAL CUT, CU. FT.
C     CTOT(I,K) = TOTAL CU. FT. REMOVED.
C     DBHE = TEMPORARY VARIABLE FOR AVERAGE STAND D.B.H. AFTER PARTIAL
C          CUTTING.
C     DBHO(I) = AVERAGE STAND D.B.H. BEFORE PARTIAL CUTTING.
C     DBHP = AVERAGE D.B.H. FROM GROWING STOCK LEVEL CURVES.
C     DBHT(I) = AVERAGE STAND D.B.H. AFTER PARTIAL CUTTING.
C     DELAY(I) = NUMBER OF YEARS BETWEEN INITIAL AGE AND FIRST PARTIAL
C          CUTTING, IF FIRST PARTIAL CUTTING IS NOT DONE AT ONCE.
C     DELDMR = CHANGE IN D.M.R. DUE TO PARTIAL CUTTING.
C     DENO(I) = TREES PER ACRE BEFORE PARTIAL CUTTING.
C     DENT(I) = TREES PER ACRE AFTER PARTIAL CUTTING.
C     DIE = TREES LOST IN DISEASED STANDS IN RINT YEARS, IN PERCENT.
C     DINC = PERIODIC INCREASE IN AVERAGE D.B.H. IN STANDS WITH D.M.R.
C          GREATER THAN 3.5.
C     DLEV(I) = GROWING STOCK LEVEL FOR INTERMEDIATE CUTS AFTER THE
C          FIRST AND FOR REGENERATION CUTS BY SEED TREE OR SHELTERWOOD.
C     DMLEV = D.M.R. ABOVE WHICH NO INTERMEDIATE CUTTING WILL BE DONE.
C     DMR(I) = DWARF MISTLETOE INFECTION RATING.
C     DMRT(I) = MAXIMUM INFECTION EXPECTED IN STANDS AFTER PARTIAL
C          CUTTING.
C     DSTY(I) = GROWING STOCK LEVEL FOR INTERMEDIATE CUTS AFTER THE
C          FIRST.
C     FCTR = FACTOR TO CONVERT TOTAL CU. FT. TO MERCH. CU. FT.
C     GSLEVL = CURRENT ACTUAL GROWING STOCK LEVEL.
C     HTNEW = ESTIMATED AVERAGE TREE HEIGHT IN STANDS WITH GROWING STOCK
C          LEVEL GREATER THAN 160.
C     HTPCT = PERCENTAGE OF POTENTIAL HEIGHT GROWTH ACTUALLY ATTAINED
C          BY INFESTED STANDS.
C     HTSO(I) = AVERAGE TREE HEIGHT BEFORE PARTIAL CUTTING.
C     HTST(I) = AVERAGE TREE HEIGHT AFTER PARTIAL CUTTING.
C     ICUT = FLAG WITH INPUT VALUE DEFINED BELOW TO CONTROL THINNINGS.
C          0 - NO NONCOMMERCIAL THINNINGS ALLOWED.
C          1 - PRECOMMERCIAL INITIAL THINNING ALLOWED. NONCOMMERCIAL
C               SUBSEQUENT THINNINGS NOT ALLOWED.
C          2 - ALL THINNINGS MAY BE NONCOMMERCIAL.
C     IK(I) = NUMBER OF GROWTH PROJECTION PERIODS IN JCYCL(I).
C     IOPT(I) = FLAG TO ALLOW (0) OR PREVENT (1) INITIAL THINNING FROM
C          ABOVE IN STANDS WITH DWARF MISTLETOE.
C     IREGN(I) = FLAG WITH A VALUE OF ONE IF A REGENERATION CUT IS BEING
C          PERFORMED.
C     ISANS(I) = FLAG WITH A VALUE EQUAL TO THE NUMBER OF GROWTH
C          PROJECTIONS SINCE A CUT WHICH REDUCES D.M.R. TO ZERO IN
C          INFESTED STANDS.
C     JCYCL(I) = INTERVAL BETWEEN INTERMEDIATE OR REGENERATION CUTS.
C     KDEL(I) = NUMBER OF PROJECTION PERIODS BEFORE INITIAL PARTIAL
C          CUTTING IS PERFORMED.
C     KOL = COUNTER TO CONTROL STORAGE IN ARRAYS PRINTED IN YIELD TABLES
C     KOUNT(I) - NUMBER OF GROWTH PROJECTIONS SINCE LAST CUT.
C     KPER = NUMBER OF PROJECTION PERIODS FROM INITIAL AGE TO CURRENT
C          AGE.
C     KSTEP(I) = INDICATOR WITH VALUE OF ONE IF CURRENT PARTIAL CUTTING
C          IS FROM BELOW AND TWO IF CURRENT PARTIAL CUTTING IS FROM
C          ABOVE.
C     KTR(I) = INDICATOR WITH VALUE GREATER THAN ZERO IF A SCHEDULED
C          THINNING HAS BEEN SKIPPED BECAUSE D.M.R. IS GREATER THAN
C          DMLEV, STAND IS ALREADY AT OR BELOW SPECIFIED STOCKING, OR
C          THINNING DID NOT MEET IMPOSED MERCHANTABILITY STANDARDS.
C     NOTE(L) = DESCRIPTION OF TEST CONDITIONS FOR STAND OUTPUT.
C     NSTND = NUMBER OF STANDS BEING PROCESSED BY RUN.
C     OUT = PERCENTAGE MORTALITY IN HEALTHY STANDS.
C     PCT = PERCENTAGE OF POTENTIAL PERIODIC HEIGHT GROWTH ACTUALLY
C          ATTAINED BY INFESTED STANDS.
C     PINF(I) = PERCENTAGE OF TREES INFECTED WITH DWARF MISTLETOE.
C     PRET = PERCENTAGE OF TREES RETAINED AFTER PARTIAL CUTTING.
C     PROD = FACTOR TO CONVERT TOTAL CU. FT. TO BD. FT.
C     REGN(J) = STAND AGE WHEN REGENERATION CUT J OCCURS.
C     REST(I) = GROWING STOCK LEVEL FOR CURRENT INTERMEDIATE CUT.
C     RINT = NUMBER OF YEARS FOR WHICH A SINGLE PROJECTION IS MADE.
C     ROTA = FINAL AGE IN YIELD TABLE.
C     ROTAOS = AGE OF OVERSTORY AT TIME OF FINAL REMOVAL IF OVERSTORY IS
C          TO BE RETAINED PAST LARGEST REGN(J).
C     SBAS = TOTAL BASAL AREA OF STAND, INCLUDING BOTH STORIES.
C     SBD(I) = SUM OF BOARD FEET FROM ALL CUTS WITH YIELD OF COMBF OR
C          LARGER.
C     SITE = SITE INDEX.
C     SMC(I) = SUM OF MERCH. CU. FT. FROM ALL CUTS WITH YIELD OF COMCU
C          OR LARGER.
C     SQFT = BASAL AREA AS A FUNCTION OF AVERAGE D.B.H. FOR GROWING
C          STOCK LEVEL 80.
C     START(I) = AGE OF STORY AT TIME OF INITIAL INFECTION.
C     STF(I) = SUM OF TOTAL CU. FT. FROM ALL CUTS.
C     STND = STAND IDENTIFICATION NUMBER.
C     TAGE(I,K) = STAND AGE AFTER CUTTING.
C     TBAS(I,K) = BASAL AREA AFTER CUTTING.
C     TBF(I,K) = M BD. FT. AFTER CUTTING.
C     TCF = TEMPORARY VARIABLE FOR TOTAL CU. FT.
C     TDEN(I,K) = NUMBER OF TREES AFTER CUTTING.
C     TDM(I,K) = AVERAGE D.B.H. AFTER CUTTING.
C     TDMR(I,K) = DWARF MISTLETOE INFECTION RATING AFTER CUTTING.
C     TEMH(L) = TEMPRORAY VARIABLES USED IN COMPUTATION OF PERIODIC
C          HEIGHT GROWTH.
C     THIN(I) = GROWING STOCK LEVEL FOR INITIAL THINNING, HEALTHY
C          STANDS.
C     THT(I,K) - AVERAGE HEIGHT AFTER CUTTING.
C     TIME = NUMBER OF YEARS STAND INFESTED BY DWARF MISTLETOE.
C     TMCF(I,K) = MERCH. CU. FT. AFTER CUTTING.
C     TTOT(I,K) = TOTAL CU. FT. AFTER CUTTING.
C     UAGE(I,K) = STAND AGE BEFORE CUTTING.
C     UBAS(I,K) = BASAL AREA BEFORE CUTTING.
C     UBF(I,K) = M BD. FT. BEFORE CUTTING.
C     UDEN(I,K) = NUMBER OF TREES BEFORE CUTTING.
C     UDM(I,K) = AVERAGE D.B.H. BEFORE CUTTING.
C     UDMR(I,K) = DWARF MISTLETOE INFECTION RATING BEFORE CUTTING.
C     UHT(I,K) - AVERAGE HEIGHT BEFORE CUTTING.
C     UMCF(I,K) = MERCH. CU. FT. BEFORE CUTTING.
C     UTOT(I,K) = TOTAL CU. FT. BEFORE CUTTING.
C     VLLV(J) = PERCENT OF PREVIOUS DLEV(I) TO BE LEFT AT REGN(J),
C          ENTERED AS A DECIMAL.
C     YDM = ANNUAL INCREASE IN DMR IN INFESTED STANDS.
C
      COMMON /BLKA/BA,DBH,DEN,HT,BDF,CFM,TCF
C
      COMMON /BLKB/BAST(2),DBHO(2),DBHT(2),DENO(2),DENT(2),DMR(2),PRET,
     1REST(2),ITM,MOL,DMLEV,IREGN(2),PINF(2),ISANS(2)
C
      COMMON /BLKC/DSTY(2),KTR(2),STND,SBD(2),SITE,SMC(2),STF(2),
     1THIN(2),VAR(22),COMBF,COMCU,START(2),NOTE(16),ICUT
C
      COMMON /BLKD/CBAS(2,20),TBAS(2,20),UBAS(2,20),CBF(2,20),TBF(2,20),
     1UBF(2,20),CDEN(2,20),TDEN(2,20),UDEN(2,20),CMCF(2,20),TMCF(2,20),U
     2MCF(2,20),CTOT(2,20),TTOT(2,20),UTOT(2,20),TAGE(2,20),UAGE(2,20),T
     3DM(2,20),UDM(2,20),THT(2,20),UHT(2,20),UDMR(2,20),TDMR(2,20)
C
      COMMON /BLKE/ADDHT(2),AGEO(2),BASO(2),DELAY(2),DLEV(2),DMRT(2),
     1HTSO(2),HTST(2),IOPT(2),JCYCL(2),JDEN(2),KOL,KSTEP(2),REGN(3),
     2RINT,ROTA,TEMH(2),TIME,VLLV(2),ROTAOS
C
      COMMON /BLKF/IK(2),KOUNT(2),SBAS,KPER,KDEL(2)
C
      NSTND = 0
      DO 10 J=16,18
      VAR(J) = 0.0
   10 CONTINUE
C
C READ NUMBER OF STANDS TO BE PROCESSED AND PROJECTION LENGTH FROM CARD
C TYPE ONE.
C
      READ (5,20) NSTND,RINT
   20 FORMAT (I5,F5.0)
      IF(NSTND .LE. 0) GO TO 120
      VAR(16) = RINT
C
C READ MINIMUM COMMERCIAL CUTS FROM CARD TYPE TWO.
C
      READ (5,30) COMCU,COMBF
   30 FORMAT (2F5.0)
      VAR(17) - COMBF
      VAR(18) = COMCU
C
C
C EXECUTE PROGRAM ONCE FOR EACH STAND.
C
      DO 110 KAN=1,NSTND
      CALL BEGIN
C
C CHECK FOR UNWANTED ZEROS OR BLANKS IN DATA.
C
      DO 40 I=1,7,2
      IF(VAR(I) .LE. 0.0) GO TO 90
   40 CONTINUE
      DO 50 I=13,19
      IF(VAR(I) .LE. 0.0) GO TO 90
   50 CONTINUE
C
C COMPUTE VALUES FOR FIRST ENTRIES IN YIELD TABLES.
C
      CALL FIRST
      SBAS = BASO(1) + BASO(2)
C
C ENTER LOOP FOR REMAINING COMPUTATIONS FOR A STAND.
```

```
C
      LIM = (ROTA - AGEO(1)) / RINT + 1.5
      IF(JDEN(2) .GT. 0) LIM = (ROTA - AGEO(2)) / RINT + 1.5
      DO 70 K=1,LIM
      KPER = K
      CALL CUTS
      SBAS = BAST(1) + BAST(2)
      CALL PROJ
      SBAS = BASO(1) + BASO(2)
   70 CONTINUE
C
C WRITE YIELD TABLES FOR A STAND.
C
      DO 80 I=1,2
      IF(AGEO(I) .LE. 0.0) GO TO 80
      MOL = I
      CALL TABLE
   80 CONTINUE
      GO TO 110
C
C PROGRAM CONTROL GOES HERE IF ANY UNWANTED ZEROS OR BLANKS ARE FOUND
C IN DATA.
C
   90 WRITE (6,100) STND
  100 FORMAT (1H1,///,10X,73HEXECUTION STOPPED BECAUSE OF NEGATIVE OR ZE
     1RO ITEM ON DATA CARDS OF STAND,F4.0)
  110 CONTINUE
      GO TO 140
  120 WRITE (6,130)
  130 FORMAT (1H1,////,30X,52HEXECUTION STOPPED BECAUSE OF ILLEGAL VALUE
     1 OF NSTND.)
  140 STOP
      END
```

```
      SUBROUTINE BEGIN
C
C TO INITIALIZE STAND VARIABLES AND READ IN STAND DATA.
C
      COMMON /BLKB/BAST(2),DBHO(2),DBHT(2),DENO(2),DENT(2),DMR(2),PRET,
     1REST(2),ITM,MOL,DMLEV,IREGN(2),PINF(2),ISANS(2)
C
      COMMON /BLKC/DSTY(2),KTR(2),STND,SBD(2),SITE,SMC(2),STF(2),
     1THIN(2),VAR(22),COMBF,COMCU,START(2),NOTE(16),ICUT
C
      COMMON /BLKD/CBAS(2,20),TBAS(2,20),UBAS(2,20),CBF(2,20),TBF(2,20),
     1UBF(2,20),CDEN(2,20),TDEN(2,20),UDEN(2,20),CMCF(2,20),TMCF(2,20),U
     2MCF(2,20),CTOT(2,20),TTOT(2,20),UTOT(2,20),TAGE(2,20),UAGE(2,20),T
     3DM(2,20),UDM(2,20),THT(2,20),UHT(2,20),UDMR(2,20),TDMR(2,20)
C
      COMMON /BLKE/ADDHT(2),AGEO(2),BASO(2),DELAY(2),DLEV(2),DMRT(2),
     1HTSO(2),HTST(2),IOPT(2),JCYCL(2),JDEN(2),KOL,KSTEP(2),REGN(3),
     2RINT,ROTA,TEMH(2),TIME,VLLV(2),ROTAOS
C
      COMMON /BLKF/IK(2),KOUNT(2),SBAS,KPER,KOEL(2)
C
      DO 10 J=1,15
      VAR(J) = 0.0
   10 CONTINUE
      DO 20 I=1,2
      ADDHT(I) = 0.0
      AGEO(I) = 0.0
      BASO(I) = 0.0
      BAST(I) = 0.0
      DBHO(I) = 0.0
      DBHT(I) = 0.0
      DELAY(I) = 0.0
      DENO(I) = 0.0
      DENT(I) = 0.0
      DLEV(I) = 0.0
      DMR(I) = 0.0
      DMRT(I) = 0.0
      DSTY(I) = 0.0
      HTSO(I) = 0.0
      HTST(I) = 0.0
      IOPT(I) = 0
      IREGN(I) = 0
      ISANS(I) = 1000
      JCYCL(I) = 0
      JDEN(I) = 0
      KOUNT(I) = 1000
      KSTEP(I) = 1
      KTR(I) = 0
      PINF(I) = 0.0
      REST(I) = 0.0
      SBD(I) = 0.0
      SMC(I) = 0.0
      START(I) = 0.0
      STF(I) = 0.0
      THIN(I) = 0.0
      VLLV(I) = 0.0
   20 CONTINUE
      DO 30 I=1,3
      REGN(I) = 0.0
   30 CONTINUE
      DO 40 I=1,2
      DO 40 J=1,20
      CBAS(I,J) = 0.0
      CBF(I,J) = 0.0
      CDEN(I,J) = 0.0
      CMCF(I,J) = 0.0
      CTOT(I,J) = 0.0
      TAGE(I,J) = 0.0
      TBAS(I,J) = 0.0
      TBF(I,J) = 0.0
      TDEN(I,J) = 0.0
      TDM(I,J) = 0.0
      TDMR(I,J) = 0.0
      THT(I,J) = 0.0
      TMCF(I,J) = 0.0
      TTOT(I,J) = 0.0
      UAGE(I,J) = 0.0
      UBAS(I,J) = 0.0
      UBF(I,J) = 0.0
      UDEN(I,J) = 0.0
      UDM(I,J) = 0.0
      UDMR(I,J) = 0.0
      UHT(I,J) = 0.0
      UMCF(I,J) = 0.0
      UTOT(I,J) = 0.0
   40 CONTINUE
      DMLEV = 0.0
      ICUT = 0
      STND = 0.0
      TIME = 0.0
C
C READ TEST DESCRIPTION FROM CARD TYPE THREE.
C
      READ (5,50) (NOTE(I),I=1,16)
   50 FORMAT (16A5)
C
C READ INTERMEDIATE CUT INSTRUCTIONS FROM CARD TYPE FOUR.
C
      READ (5,60) ICUT,DMLEV,DELAY(1),IOPT(1),THIN(1),DSTY(1),JCYCL(1),
     1DELAY(2),IOPT(2),THIN(2),DSTY(2),JCYCL(2)
   60 FORMAT (I5,F5.1,2(F5.0,I5,2F5.0,I5))
      ICUT = ICUT + 1
C
C STORE INITIAL VALUES FOR ERROR CHECKS AND LATER USE.
C
      VAR(7) = JCYCL(1)
      IF(JCYCL(2) .LE. 0) JCYCL(2) = JCYCL(1)
      VAR(8) = JCYCL(2)
      VAR(14) = THIN(1)
      IF(THIN(2) .LE. 0.0) THIN(2) = THIN(1)
      VAR(15) = DSTY(1)
      IF(DSTY(2) .LE. 0.0) DSTY(2) = DSTY(1)
C
C READ INITIAL STAND VALUES FROM CARD TYPE FIVE.
C
      READ (5,70) STND,SITE,AGEO(1),DBHO(1),HTSO(1),DENO(1),DMR(1),
     1PINF(1),START(1),AGEO(2),DBHO(2),HTSO(2),DENO(2),DMR(2),PINF(2),
     2START(2)
   70 FORMAT (2F5.0,2(F5.0,2F5.1,F5.0,2F5.1,F5.0))
C
C STORE INITIAL VALUES FOR ERROR CHECKS AND LATER USE.
C
      VAR(1) = AGEO(1)
      VAR(2) = AGEO(2)
      VAR(3) = DBHO(1)
      VAR(4) = DBHO(2)
      VAR(5) = DENO(1)
      VAR(6) = DENO(2)
      VAR(9) = START(1)
      VAR(10) = START(2)
      VAR(11) = DMR(1)
      VAR(12) = DMR(2)
      VAR(13) = SITE
      VAR(21) = PINF(1)
      VAR(22) = PINF(2)
      JDEN(1) = DENO(1) + 0.5
      JDEN(2) = DENO(2) + 0.5
C
C READ REGENERATION CUT INSTRUCTIONS FROM CARD TYPE SIX.
C
      READ (5,80) REGN(1),VLLV(1),REGN(2),VLLV(2),REGN(3)
   80 FORMAT (F5.0,F5.3,F5.0,F5.3,F5.0)
      VAR(19) = REGN(1)
      RETURN
      END
```

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      SUBROUTINE FIRST
C
C TO COMPUTE VALUES FOR FIRST ENTRIES IN YIELD TABLES.
C
      COMMON /BLKA/BA,DBH,DEN,HT,BDF,CFM,TCF
C
      COMMON /BLKB/BAST(2),DBHO(2),DBHT(2),DENO(2),DENT(2),DMR(2),PRET,
     1REST(2),ITM,MOL,DMLEV,IREGN(2),PINF(2),ISANS(2)
C
      COMMON /BLKC/DSTY(2),KTR(2),STND,SBD(2),SITE,SMC(2),STF(2),
     1THIN(2),VAR(22),COMBF,COMCU,START(2),NOTE(16),ICUT
C
      COMMON /BLKD/CBAS(2,20),TBAS(2,20),UBAS(2,20),CBF(2,20),TBF(2,20),
     1UBF(2,20),CDEN(2,20),TDEN(2,20),UDEN(2,20),CMCF(2,20),TMCF(2,20),U
     2MCF(2,20),CTOT(2,20),TTOT(2,20),UTOT(2,20),TAGE(2,20),UAGE(2,20),T
     3DM(2,20),UDM(2,20),THT(2,20),UHT(2,20),UDMR(2,20),TDMR(2,20)
C
      COMMON /BLKE/ADDHT(2),AGEO(2),BASO(2),DELAY(2),DLEV(2),DMRT(2),
     1HTSO(2),HTST(2),IOPT(2),JCYCL(2),JDEN(2),KOL,KSTEP(2),REGN(3),
     2RINT,ROTA,TEMH(2),TIME,VLLV(2),ROTAOS
C
      COMMON /BLKF/IK(2),KOUNT(2),SBAS,KPER,KOEL(2)
C
      KOL = 1
      IRINT = RINT
C
C IDENTIFY FINAL AGE IN YIELD TABLE.
C
      DO 10 NA=1,3
      L = 4 - NA
      IF(REGN(L) .GT. 0.0) GO TO 20
   10 CONTINUE
   20 ROTA = REGN(L)
      VAR(20) = ROTA
      ROTAOS = AGEO(1) + DELAY(1)
      IF(ROTAOS .LT. ROTA) ROTAOS = ROTA
C
C COMPUTE VALUES OF STAND CHARACTERISTICS, ONE STORY AT A TIME.
C
      DO 140 I=1,2
      IF(JDEN(I) .EQ. 0) GO TO 140
C
C COMPUTE INITIAL D.M.R. IF ONLY INFECTION TIME OR INITIAL PERCENT
C INFECTED REPORTED.
C
      IF(DMR(I) .GT. 0.0) GO TO 70
      IF(PINF(I) .LE. 0.0) GO TO 40
      DMR(I) = 10.0 ** (-0.94652 + 0.01651 * PINF(I))
      GO TO 70
   40 TIME = AGEO(I) - START(I)
      IF(TIME .LE. 0.0) GO TO 100
      IF(I .EQ. 2) GO TO 60
      DMR(1) = 0.120055 * TIME - 0.961031 * TIME / DENO(1) - 0.003420 *
     1 TIME * SITE
      GO TO 70
   60 IF(DENO(2) .GT. 3000.0) GO TO 65
      DMR(2) = 0.087923 * TIME - 0.000018 * TIME * DENO(2) + 0.000051 *
     1 TIME * DMR(1) * DMR(1) * DENO(1)
      GO TO 70
   65 DMR(2) = 0.0441757 * TIME - 0.0000034 * TIME * DENO(2) +
     1 0.000051 * TIME * DMR(1) * DMR(1) * DENO(1)
   70 IF(DMR(I) .LT. 0.0) DMR(I) = 0.0
      IF(DMR(I) .GT. 6.0) DMR(I) = 6.0
      IF(DMR(I) .GT. 0.0) START(I) = 10000.0

COMPUTE INITIAL AVERAGE HEIGHT IF NOT REPORTED.

  100 IF(HTSO(I) .GT. 0.0) GO TO 130
      IF(AGEO(I) .GT. 55.0) GO TO 110
      HTSO(I) = 0.01441 * AGEO(I) * SITE - 0.12167 * AGEO(I) - 1.50953
      GO TO 120
  110 HTSO(I) = 0.59947 - 61.5019 / AGEO(I) + 0.80522 * ALOG10(SITE) +
     1 20.52528 * ALOG10(SITE) / AGEO(I)
      HTSO(I) = 10.0 ** HTSO(I)
  120 HTPCT = 1.073 - 0.0367 * DMR(I)
      IF(HTPCT .GT. 1.0) HTPCT = 1.0
      HTSO(I) = HTSO(I) * HTPCT

COMPUTE INITIAL BASAL AREA AND VOLUMES.

  130 BASO(I) = DENO(I) * 0.0054542 * DBHO(I) * DBHO(I)
      BA = BASO(I)
      DBH = DBHO(I)
      DEN = DENO(I)
      HT = HTSO(I)
      CALL SWVOL

STORE VALUES FOR PRINTING.

      UAGE(I,KOL) = AGEO(I) + 0.5
      MAX = DMR(I) * 10.0 + 0.5
      UDMR(I,KOL) = MAX
      UDMR(I,KOL) = UDMR(I,KOL) * 0.1
      UDEN(I,KOL) = DENO(I)
      MAX = BASO(I) + 0.5
      UBAS(I,KOL) = MAX
      UDM(I,KOL) = DBHO(I)
      MAX = HTSO(I) + 0.5
      UHT(I,KOL) = MAX
      MAX = (TCF * 0.1) + 0.5
      UTOT(I,KOL) = MAX * 10
      MAX = (CFM * 0.1) + 0.5
      UMCF(I,KOL) = MAX * 10
      MAX = (BDF * 0.01) + 0.5
      UBF(I,KOL) = MAX * 100
C
COMPUTE VALUES OF NEEDED CONTROL VARIABLES.
C
      IK(I) = JCYCL(I) / IRINT
      ITEM = (REGN(1) - AGEO(I)) / RINT + 0.5
      IF(IK(I) .GT. ITEM) IK(I) = ITEM
      KDEL(I) = DELAY(I) / RINT + 0.5
      REST(I) = THIN(I)
      DLEV(I) = DSTY(I)
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CUTS
C
C  CONTROL EXECUTION OF INTERMEDIATE AND REGENERATION CUTS.
C
      COMMON /BLKA/BA,DBH,DEN,HT,BDF,CFM,TCF
C
      COMMON /BLKB/BAST(2),DBHO(2),DBHT(2),DENO(2),DENT(2),DMR(2),PRET,
     1REST(2),ITM,MOL,DMLEV,IREGN(2),PINF(2),ISANS(2)
C
      COMMON /BLKC/DSTY(2),KTR(2),STND,SBD(2),SITE,SMC(2),STF(2),
     1THIN(2),VAR(22),COMBF,COMCU,START(2),NOTE(16),ICUT
C
      COMMON /BLKD/CBAS(2,20),TBAS(2,20),UBAS(2,20),CBF(2,20),TBF(2,20),
     1UBF(2,20),CDEN(2,20),TDEN(2,20),UDEN(2,20),CMCF(2,20),TMCF(2,20),U
     2MCF(2,20),CTOT(2,20),TTOT(2,20),UTOT(2,20),TAGE(2,20),UAGE(2,20),T
     3DM(2,20),UDM(2,20),THT(2,20),UHT(2,20),UDMR(2,20),TDMR(2,20)
C
      COMMON /BLKE/ADDHT(2),AGEO(2),BASO(2),DELAY(2),DLEV(2),DMRT(2),
     1HTSO(2),HTST(2),IOPT(2),JCYCL(2),JDEN(2),KOL,KSTEP(2),REGN(3),
     2RINT,ROTA,TEMH(2),TIME,VLLV(2),ROTADS
C
      COMMON /BLKF/IK(2),KOUNT(2),SBAS,KPER,KDEL(2)
C
      IRINT = RINT + 0.5
C
C  MPUTE VALUES OF STAND CHARACTERISTICS, ONE STORY AT A TIME.
C
      DO 230 I=1,2
      IF(JDEN(I) .EQ. 0) GO TO 230
      IF(I .EQ. 1 .AND. AGEO(1) .GE. ROTADS) GO TO 210
      IF(I .EQ. 2 .AND. AGEO(2) .GE. ROTA) GO TO 210
      BAST(I) = BASO(I)
      DBHT(I) = DBHO(I)
      DENT(I) = DENO(I)
      DMRT(I) = DMR(I)
      HTST(I) = HTSO(I)
      IF(KPER .LE. KDEL(I)) GO TO 230
      IF(KOUNT(I) .LT. IK(I)) GO TO 230
C
C DEFINE INTERVAL TO FIRST REGENERATION CUT IF LESS THAN CURRENT
C  TING CYCLE.
C
      ITEM = (REGN(1) - AGEO(I)) / RINT + 0.5
      IF(IREGN(I) .EQ. 0 .AND. IK(I) .GT. ITEM) IK(I) = ITEM
      IREGN(I) = 0
      ITM = I
      KOUNT(I) = 0
      TAGE(I,KOL) = AGEO(I) + 0.5
C
C  NGE CUTTING STANDARDS IF A REGENERATION CUT IS DUE.
C
      IF(AGEO(I) .LT. REGN(1)) GO TO 20
      DO 10 L=1,2
      IF(AGEO(I) .NE. REGN(L)) GO TO 10
      DLEV(I) = DLEV(I) * VLLV(L)
      REST(I) = DLEV(I)
      JCYCL(I) = REGN(L+1) - REGN(L) + 0.5
      IK(I) = JCYCL(I) / IRINT
      IREGN(I) = 1
      GO TO 20
   10 CONTINUE
C
C COMPUTE CURRENT GROWING STOCK LEVEL TO DETERMINE IF STORY IS ALREADY
C AT OR BELOW DESIRED STOCKING LEVEL.
C
   20 IF(DBHO(I) .GT. 2.0) GO TO 22
      GSLEVL = 80.0 * BASO(I) / (6.03633 * DBHO(I))
      GO TO 40
   22 IF(DBHO(I) .GE. 5.0) GO TO 25
      GSLEVL = 80.0 * BASO(I) / (11.58495 * DBHO(I) - 11.09724)
      GO TO 40
   25 IF(DBHO(I) .GT. 10.0) GO TO 30
      TEM = DBHO(I) * DBHO(I)
      GSLEVL = 80.0 * BASO(I) / (7.76226 * DBHO(I) + 0.85283 * TEM -
     1 0.07952 * TEM * DBHO(I) - 3.45624)
      GO TO 40
   30 GSLEVL = BASO(I)
C
C CHANGE D.B.H. AND D.M.R. BY PARTIAL CUTTING.
C
   40 IF(DMR(I) .LE. 0.0) GO TO 70
      IF(IREGN(I) .EQ. 1) GO TO 70
      IF(DMR(I) .GT. DMLEV) GO TO 180
      IF(IOPT(I) .GT. 0) GO TO 70
      IF(KPER .GT. (KDEL(I) + 1)) GO TO 70
C
C COMPUTE INITIAL THINNING LEVEL IF THINNING FROM ABOVE. EXECUTE
C THINNING FROM ABOVE.
C
   50 IF(THIN(I) .LE. 60.0) GO TO 60
      REST(I) = THIN(I) - (DMR(I) * (THIN(I) - 60.0) / 3.0)
      IF(DMR(I) .GT. 3.0) REST(I) = 60.0
   60 IF(GSLEVL .LE. REST(I)) GO TO 180
      CALL SWCUT2
      KSTEP(I) = 2
      GO TO 90
C
C EXECUTE PARTIAL CUTTING FROM BELOW.
C
   70 IF(GSLEVL .LE. REST(I)) GO TO 180
      CALL SWCUT1
      IF(PRET .GE. 100.0) GO TO 180
      KSTEP(I) = 1
   90 IF(BAST(I) .GE. BASO(I)) GO TO 180
C
C COMPUTE D.M.R. AFTER PARTIAL CUTTING.
C
      DMRT(I) = DMR(I)
      IF(DMR(I) .LE. 0.0) GO TO 110
      DELOMR = 2.92759 + 0.06144 * DMR(I) * DMR(I) - 0.75986 *
     1 SQRT(PRET) - 0.00882 * DMR(I) * DMR(I) * SQRT(PRET)
      IF(KSTEP(I) .EQ. 1) DELOMR = DELOMR * 0.66667
      IF(DELOMR .LT. 0.0) DELOMR = 0.0
      DMRT(I) = DMR(I) - DELOMR
      IF(DMRT(I) .LT. 0.0) DMRT(I) = 0.0
      IF(DMRT(I) .GT. 6.0) DMRT(I) = 6.0
C
C COMPUTE HEIGHT, BASAL AREA, DENSITY, AND VOLUMES AFTER PARTIAL CUTTING
C
  110 KS = KSTEP(I)
      GO TO (120,130), KS
  120 ADDHT(I) = 7.64833 - 3.42286 * ALOG10(PRET)
      GO TO 140
  130 ADDHT(I) = 2.43837 * ALOG10(PRET) + 1.64026 * ALOG10(BAST(I))
     1 - 8.47960
  140 HTST(I) = HTSO(I) + ADDHT(I)
      JDENT = BAST(I) / (0.0054542 * DBHT(I) * DBHT(I)) + 0.5
      DENT(I) = JDENT
      BAST(I) = 0.0054542 * DBHT(I) * DBHT(I) * DENT(I)
      BA = BAST(I)
      DBH = DBHT(I)
      DEN = DENT(I)
      HT = HTST(I)
      CALL SWVOL
C
C CHECK TO SEE IF INTERMEDIATE CUT SATISFIES COMMERCIAL CRITERIA, IF
C ANY.  DO NOT CUT IF COMMERCIAL CRITERIA NOT SATISFIED.
C STORE VALUES FOR PRINTING.
C
      MAX = CFM * 0.1 + 0.5
      TMCF(I,KOL) = MAX * 10
      IF(TMCF(I,KOL) .GT. UMCF(I,KOL)) UMCF(I,KOL) = TMCF(I,KOL)
      CMCF(I,KOL) = UMCF(I,KOL) - TMCF(I,KOL)
      MAX = BDF * 0.01 + 0.5
      TBF(I,KOL) = MAX * 100
      IF(TBF(I,KOL) .GT. UBF(I,KOL)) UBF(I,KOL) = TBF(I,KOL)
      CBF(I,KOL) = UBF(I,KOL) - TBF(I,KOL)
      IF(IREGN(I) .EQ. 1) GO TO 190
      GO TO (170,160,190), ICUT
  160 IF(KPER .EQ. (KDEL(I) + 1)) GO TO 190
  170 IF(CBF(I,KOL) .GE. COMBF) GO TO 190
      IF(CMCF(I,KOL) .GE. COMCU) GO TO 190
  180 BAST(I) = BASO(I)
      DBHT(I) = DBHO(I)
      DENT(I) = DENO(I)
      DMRT(I) = DMR(I)
      HTST(I) = HTSO(I)
      KTR(I) = 1
      TBAS(I,KOL) = UBAS(I,KOL)
      TBF(I,KOL) = UBF(I,KOL)
      TDEN(I,KOL) = UDEN(I,KOL)
      TDM(I,KOL) = UDM(I,KOL)
      TDMR(I,KOL) = UDMR(I,KOL)
      THT(I,KOL) = UHT(I,KOL)
      TMCF(I,KOL) = UMCF(I,KOL)
      TTOT(I,KOL) = UTOT(I,KOL)
      CBAS(I,KOL) = 0.0
      CBF(I,KOL) = 0.0
      CDEN(I,KOL) = 0.0
      CMCF(I,KOL) = 0.0
      CTOT(I,KOL) = 0.0
      GO TO 230
  190 TDEN(I,KOL) = DENT(I)
      MAX = DMRT(I) * 10.0 + 0.5
      TDMR(I,KOL) = MAX
      TDMR(I,KOL) = TDMR(I,KOL) * 0.1
      MAX = HTST(I) + 0.5
      THT(I,K,L) = MAX
      MAX = HAHT(I) + 0.5
      THAS(I,K,L) = MAX
      MAX = TIF * 0.1 + 0.5
      TTIF(I,K,L) = MAX * 10
      TEM(I,K,L) = [illegible]
      [illegible]N(I,K,L) = [illegible]N(I,K,L) - TEMN(I,K,L)
      [illegible]AS(I,K,L) = [illegible]AS(I,K,L) - THAS(I,K,L)
      TIST(I,K,L) = [illegible]IST(I,K,L) - TTIST(I,K,L)
      IF(DMHR(I) .LT. 0.0) GO TO 210
C
C COMPUTE PERCENTAGE OF [illegible] THE PARTIAL CUT.
C
      FINF(I) = 67.5[illegible] + [illegible] * ALOG10(DMHR(I))
      IF(FINF(I) .LT. 0.0) FINF(I) = 0.0
      IF(FINF(I) .GT. 100.0) FINF(I) = 100.0
      IF(DMHT(I) .GT. 0.0) IDANG(I) = 0
C
C ADD [illegible] TO TOTAL YIELDS.
C
  190 TIF(I) = TIF(I) + [illegible]T(I,K,L)
      IF(DMHF(I,K,L) .LT. [illegible]) GO TO 200
      [illegible]H(I) = [illegible]H(I) + [illegible](I,K,L)
  200 IF([illegible](I,K,L) .LT. [illegible]) GO TO 230
      [illegible](I) = [illegible](I) + [illegible](I,K,L)
      GO TO 230
C
C [illegible] STAND I IF STAND HAS [illegible].
C
  210 [illegible]T(I) = 0.0
      [illegible]HT(I) = 0.0
      [illegible]NT(I) = 0.0
      [illegible]HRT(I) = 0.0
      HTST(I) = 0.0
      [illegible](I) = 0.0
      [illegible]H(I) = 0.0
      [illegible]N(I) = 0.0
      [illegible]R(I) = 0.0
      HTS[illegible](I) = 0.0
      DEN(I) = 0
C
C ADD FINAL [illegible] TO TOTAL YIELDS.
C
      [illegible]TF(I) = [illegible]TF(I) + [illegible]T(I,K,L)
      IF(DMH[illegible](I,K,L) .LT. [illegible]) GO TO 220
      [illegible](I) = [illegible](I) + [illegible](I,K,L)
  220 IF([illegible](I,K,L) .LT. [illegible]) GO TO 230
      [illegible](I) = [illegible](I) + [illegible](I,K,L)
  230 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE [illegible]
C TO MAKE PERI[illegible] GROWTH PROJECTIONS.
C
      COMMON /[illegible]/ [illegible]
C
      COMMON /[illegible]/ [illegible]
     1[illegible]
C
      COMMON /[illegible]/ [illegible]
     1[illegible]
C
      COMMON /[illegible]/ [illegible]
     1[illegible]
     2[illegible]
     3[illegible]
C
      COMMON /[illegible]/ [illegible]
     1[illegible]
     2[illegible]
C
      COMMON /[illegible]/ [illegible]
C
      K[illegible] = K[illegible] + 1
C
C COMPUTE [illegible] OF [illegible] AT A TIME.
C
      [illegible] 1,[illegible]
      IF([illegible]) GO TO [illegible]
      A[illegible](I) = A[illegible](I) + PINT
      [illegible]NT(I) = [illegible]NT(I) + 1
C
C COMPUTE CURRENT DWARF MISTLETOE RATING.
C
      IDANG(I) = IDANG(I) + 1
      IF(IDANG(I) .GT. 2) GO TO [illegible]
      [illegible] = IDANG(I)
      FP = [illegible] * FP * PINT
      DMR(I) = 10.0 ** (-[illegible] + 0.01551 * (PINF(I) * FP))
      GO TO [illegible]
      IF(DMRT(I) .GT. 0.0) GO TO 20
      DMR(I) = 0.0
      TIME = [illegible](I) - START(I)
      IF(TIME .[illegible]. 0.0) GO TO [illegible]
      IF(I .[illegible]. 2 .AND. DENT(1) .GT. 0) GO TO 10
      DMR(I) = [illegible].12[illegible]55 * TIME - 0.0[illegible]1[illegible]31 * TIME / [illegible](I) - [illegible] *
     1 TIME * SITE
      GO TO [illegible]
   10 IF([illegible]NT(2) .[illegible]. 3000.0) GO TO 15
      DMR(1) = 0.0[illegible]8[illegible]423 * TIME - 0.0[illegible]1[illegible] * TIME * [illegible]T(1) + 0.0[illegible]1 *
     1 TIME * DMRT(1) * DMRT(1) * DENT(1)
      GO TO [illegible]
   15 DMR(2) = 0.0[illegible]441757 * TIME - 0.0000003[illegible] * TIME * DENT(2) +
     1 0.0000[illegible] * TIME * DMRT(1) * DMRT(1) * DENT(1)
      GO TO 5[illegible]
   20 IF(I .EQ. [illegible] .AND. DENT(2) .GT. 0) GO TO 30
      IF(DENT(I) .LT. 1[illegible].0) GO TO 25
      YOM = 0.1[illegible]55 - 0.[illegible]1031 / DENT(I) - 0.0000[illegible] * SITE
      GO TO 40
   25 YOM = 0.0[illegible]
      GO TO 40
   30 IF(DENT(2) .GT. 3000.0) GO TO 35
      YOM = 0.0[illegible]8[illegible]423 - 0.0000016 * DENT(2) + 0.0000051 * DMRT(1) * DMRT(1)
     1 * DENT(1)
      GO TO 40
   35 YOM = 0.0441757 - 0.0000034 * DENT(2) + 0.0000051 * DMRT(1) *
     1 DMRT(1) * DENT(1)
   40 IF(DMRT(I) .GT. 1.0 .AND. DMRT(I) .LT. 4.5) GO TO 50
      IF(I .EQ. 2 .AND. DENT(2) .GT. 3000.0) GO TO 50
      DMR(I) = DMRT(I) + 0.5 * YOM * PINT
      GO TO 60
   50 DMR(I) = DMRT(I) + YOM * PINT
   60 IF(DMR(I) .LT. DMRT(I)) DMR(I) = DMRT(I)
      IF(DMR(I) .LT. 0.0) DMR(I) = 0.0
      IF(DMR(I) .GT. 6.0) DMR(I) = 6.0
      IF(DMR(I) .GT. 0.0) START(I) = 10000.0
C
C COMPUTE CURRENT ACTUAL GROWING STOCK LEVEL.
C
   70 IF(DBHT(I) .GT. 2.0) GO TO 72
      GSLEVL = 80.0 * SBAS / (6.03533 * DBHT(I))
      GO TO 90
   72 IF(DBHT(I) .GT. 5.0) GO TO 75
      GSLEVL = 80.0 * SBAS / (11.58435 * DBHT(I) - 11.[illegible])
      GO TO 90
   75 IF(DBHT(I) .GT. 10.0) GO TO 8[illegible]
      TEM = DBHT(I) * DBHT(I)
      GSLEVL = 80.0 * SBAS / (7.7[illegible] * DBHT(I) + 0.[illegible] * TEM - 0.[illegible]
     12 * TEM * DBHT(I) - 2.[illegible])
      GO TO 90
   8[illegible] GSLEVL = SBAS
C
C COMPUTE NEW D.B.H. AT END OF GROWTH PROJECTION PERIOD.
C
   90 IF(GSLEVL .GT. 150.0) GO TO 100
      DBHN(I) = 1.0047 * DBHT(I) + 0.[illegible] * SITE - 0.[illegible] * [illegible]
     1 + 3.30[illegible]
      GO TO 110
  100 DBHN(I) = 0.88511 * DBHT(I) + 1.[illegible] * ALOG10(HTST(I)) + 0.0[illegible]11
     1 * DBHT(I) * SITE + 62.57174 / SBAS - 1.[illegible]
  110 IF(DMRT(I) .LT. 3.0) GO TO 120
      DIN = (DBHN(I) - DBHT(I)) * (1.147 - 0.[illegible] * DMRT(I))
      DBHN(I) = DBHT(I) + DIN
  120 IDBH(I) = DBHN(I) * 10.0 + 0.5
      DBHN(I) = IDBH(I)
      DBHN(I) = DBHN(I) * 0.1
C
C COMPUTE CURRENT NUMBER OF TREES PER ACRE AND BASAL AREA.
C
      DIE = 0.0
      IF(DMRT(I) .LT. 1.0) GO TO 130
      IF(DENT(I) .LT. 500.0 .AND. DMRT(I) .LT. 4.0) GO TO 130
      DIE = [illegible] + 4.4[illegible] * DMRT(I) - 0.[illegible]37[illegible] * SITE + [illegible] *
     1 ALOG10(DENT(I))
      DIE = DIE * 0.01
      IF(DIE .LT. 0.0) DIE = 0.0
  130 DIT = 0.0
      IF(DBHT(I) .GT. 10.0) GO TO 140
      DIT = 0.0[illegible]247 + 0.00[illegible] * DBHT(I) + 0.[illegible] * DBHT(I) * DBHT(I) +
     1 0.[illegible]1 * SBAS * SBAS - 0.0[illegible]5 * DBHT(I) * SBAS
      IF(DIT .LT. 0.0) DIT = 0.0
  140 IF(DIE .LT. DIT) DIE = DIT
      DENN = DENT(I) * (1.0 - DIE) + 0.5
      DEN(I) = DENN
      BA(I) = DEN(I) * 0.0054542 * DBHN(I) * DBHN(I)
C
C COMPUTE CURRENT AVERAGE HEIGHT.
C
      IF(GSLEVL .GT. 150.0) GO TO 200
      DO 190 J = 1,2
      L = [illegible]J
      GO TO (150,160), L
  150 YARS = [illegible](I)
      GO TO 170
  160 YARS = [illegible](I) - PINT
  170 IF(YARS .GT. [illegible]) GO TO 180
      TEMH(J) = 0.01441 * YARS * SITE - 0.1[illegible] * YARS - 1.[illegible]
      GO TO 190
  180 TEMH(J) = 1.59947 - 41.[illegible] / YARS + 0.[illegible] * [illegible] +
     1 [illegible] * ALOG10(SITE) / YARS
      TEMH(J) = 10.0 ** TEMH(J)
  190 CONTINUE
      CHNG = TEMH(1) - TEMH(2)
      GO TO 210
  200 HTNEW = 1[illegible]0[illegible]1 + 1.1[illegible]7 * HTST(I) - 0.0[illegible] * [illegible](I) - [illegible].1[illegible]
     1 / SITE - 0.0002447 * SITE * SBAS
      CHNG = HTNEW - HTST(I)
  210 PCT = 1.0 - 0.0000[illegible] * DMRT(I) * DMRT(I) * DMRT(I)
      HTS[illegible](I) = HTST(I) + CHNG * PCT
C
C COMPUTE TOTAL CU. FT. AND CONVERT TO OTHER UNITS.
C
      [illegible] = [illegible](I)
      [illegible] = [illegible](I)
      DEN = DEN(I)
      HT = HT[illegible](I)
      CALL [illegible]
C
C STORE VALUES FOR PRINTING.
C
      [illegible](I,K,L) = AGE(I) + 0.
      MAX = DBHN(I) * 10.0 + 0.5
      [illegible](I,K,L) = MAX
      [illegible](I,K,L) = [illegible](I,K,L) * 0.1
      [illegible](I,K,L) = [illegible](I)
      MAX = [illegible](I) + 0.5
      [illegible]AS(I,K,L) = MAX
      [illegible]H(I,K,L) = [illegible](I)
      MAX = HT[illegible](I) + 0.5
      [illegible]T(I,K,L) = MAX
      MAX = TIF * 0.1 + 0.5
      [illegible]T(I,K,L) = MAX * 10
      MAX = [illegible] * 0.1 + 0.5
      [illegible]F(I,K,L) = MAX * 10
      MAX = [illegible] * 0.01 + 0.5
      [illegible]F(I,K,L) = MAX * 100
      IF(KPER .[illegible]. K[illegible](I)) [illegible]T(I) = [illegible](I)
  230 CONTINUE
      RETURN
      END
      SUBROUTINE TABLE
C
C TO PRINT YIELD TABLES AND TABLE FOOTNOTES.
C
      COMMON /BLKB/BAST(2),DBHO(2),DBHT(2),DENO(2),DENT(2),DMR(2),PRET,
     1REST(2),ITM,MOL,DMLEV,IREGN(2),PINF(2),ISANS(2)
C
      COMMON /BLKC/DSTY(2),KTR(2),STNO,SBD(2),SITE,SMC(2),STF(2),
     1THIN(2),VAR(22),COMBF,COMCU,START(2),NOTE(16),ICUT
C
      COMMON /BLKD/CBAS(2,20),TBAS(2,20),UBAS(2,20),CBF(2,20),TBF(2,20),
     1UBF(2,20),CDEN(2,20),TDEN(2,20),UDEN(2,20),CMCF(2,20),TMCF(2,20),U
     2MCF(2,20),CTOT(2,20),TTOT(2,20),UTOT(2,20),TAGE(2,20),UAGE(2,20),T
     3DM(2,20),UDM(2,20),THT(2,20),UHT(2,20),UDMR(2,20),TDMR(2,20)
C
      COMMON /BLKE/ADDHT(2),AGEO(2),BASO(2),DELAY(2),DLEV(2),DMRT(2),
     1HTSO(2),HTST(2),IOPT(2),JCYCL(2),JDEN(2),KOL,KSTEP(2),REGN(3),
     2RINT,ROTA,TEMH(2),TIME,VLEV(2),ROTADS
C
      JSITE = SITE
      I = MOL
C
C PRINT HEADINGS FOR YIELD TABLE.
C
      IF(I .EQ. 2) GO TO 30
      IF(UDEN(2,1) .GT. 0.0) GO TO 10
      WRITE (6,5) STNO
    5 FORMAT (1H1,//,32X,60HYIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PI
     1NE, STAND NUMBER,F7.0)
      GO TO 20
   10 WRITE (6,15) STNO
   15 FORMAT (1H1,//,26X,60HYIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PI
     1NE, STAND NUMBER,F7.0,12H, OVERSTORY.)
   20 WRITE (6,25) JSITE,THIN(1),DSTY(1)
   25 FORMAT (1H0,58X,10HSITE INDEX,I4/1X ,38X,29HTHINNING INTENSITY-- I
     1NITIAL-,F6.0,12H SUBSEQUENT-,F6.0)
      GO TO 50
   30 WRITE (6,40) STNO
   40 FORMAT (1H1,//,26X,60HYIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PI
     1NE, STAND NUMBER,F7.0,13H, UNDERSTORY.)
      WRITE (6,25) JSITE,THIN(2),DSTY(2)
   50 WRITE (6,60) (NOTE(J),J=1,16)
   60 FORMAT (1H0,25X,16A5)
      WRITE (6,70)
   70 FORMAT (1H0,21X,41HCHARACTERISTICS BEFORE AND AFTER THINNING,30X,2
     16HPERIODIC INTERMEDIATE CUTS)
      WRITE (6,80)
   80 FORMAT (1H0,4X,5HSTAND,15X,5HBASAL,3X,7HAVERAGE,2X,7HAVERAGE,3X,5H
     1TOTAL,3X,9HMERCHANT-,3X,9HSAWTIMBER,9X,5HBASAL,4X,5HTOTAL,3X,9HMER
     2CHANT-,3X,9HSAWTIMBER)
      WRITE (6,90)
   90 FORMAT  (1H ,5X,3HAGE,9X,5HTREES,3X,4HAREA,4X,5HD.B.H.,3X,6HHEIGHT
     1,2X,6HVOLUME,2X,11HABLE VOLUME,4X,6HVOLUME,3X,5HTREES,3X,4HAREA,3X
     2,6HVOLUME,2X,11HABLE VOLUME,4X,6HVOLUME)
      WRITE (6,100)
  100 FORMAT (1H ,3X,7H(YEARS),2X,3HDMR,3X,3HNO.,3X,5HSQ.FT.,4X,3HIN.,6X
     1,3HFT.,4X,6HCU.FT.,5X,6HCU.FT.,6X,6HBD.FT.,4X,3HNO.,3X,6HSQ.FT.,2X
     2,6HCU.FT.,5X,6HCU.FT.,6X,5HBD.FT.)
C
C PRINT TABLE ENTRIES OF STAND CHARACTERISTICS.
C
      DO 150 N=1,20
      JAGEO = UAGE(I,N)
      IF(JAGEO .EQ. 0) GO TO 120
      JDENO = UDEN(I,N)
      JBASO = UBAS(I,N)
      DIAM = UDM(I,N)
      JHTSO = UHT(I,N)
      JTOTO = UTOT(I,N)
      JCFMO = UMCF(I,N)
      JBDFO = UBF(I,N)
      WDMR = UDMR(I,N)
      WRITE (6,110) JAGEO,WDMR,JDENO,JBASO,DIAM,JHTSO,JTOTO,JCFMO,JBDFO
  110 FORMAT (1H0,4X,I4,2X,F5.1,2X,I5,2X,I4,5X,F5.1,5X,I3,4X,I5,6X,I5,6X
     1,I6)
  120 JAGEO = TAGE(I,N)
      IF(JAGEO .EQ. 0) GO TO 150
      JDENT = TDEN(I,N)
      JBAST = TBAS(I,N)
      DMTR = TDM(I,N)
      JHTST = THT(I,N)
      JTOTT = TTOT(I,N)
      JCFMT = TMCF(I,N)
      JBDFT = TBF(I,N)
      JDENC = CDEN(I,N)
      JBASC = CBAS(I,N)
      JTOTC = CTOT(I,N)
      JCFMC = CMCF(I,N)
      JBDFC = CBF(I,N)
      WDMRT = TDMR(I,N)
      WRITE (6,130) JAGEO,WDMRT,JDENT,JBAST,DMTR,JHTST,JTOTT,JCFMT,JBDFT
     1,JDENC,JBASC,JTOTC,JCFMC,JBDFC
  130 FORMAT (1H ,4X,I4,2X,F5.1,2X,I5,2X,I4,5X,F5.1,5X,I3,4X,I5,6X,I5,6X
     1,I6,4X,I5,3X,I3,5X,I4,6X,I4,8X,I5)
  150 CONTINUE
      JSTF = STF(I)
      JSMC = SMC(I)
      JSBD = SBD(I)
      WRITE (6,160) JSTF,JSMC,JSBD
  160 FORMAT (1H0,/,67X,12HTOTAL YIELDS,13X,I5,5X,I5,7X,I6)
C
C PRINT APPROPRIATE FOOTNOTES FOR TABLE.
C
      WRITE (6,170)
  170 FORMAT (1H0,//,11X,68HMERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND
     1 LARGER TO 4.0-INCH TOP.)
      WRITE (6,180)
  180 FORMAT (1H ,10X,68HBD. FT. - TREES 10.0 INCHES D.B.H. AND LARGER T
     1O VARIABLE TOP LIMIT.)
      IF(IOPT(I) .GT. 0) GO TO 200
      WRITE (6,190)
  190 FORMAT (1H ,10X,67HINITIAL THINNING FROM ABOVE ALLOWED IN STANDS W
     1ITH DWARF MISTLETOE.)
      GO TO 220
  200 WRITE (6,210)
  210 FORMAT (1H ,10X,36HINITIAL THINNING MUST BE FROM BELOW.)
  220 WRITE (6,230) DMLEV
  230 FORMAT (1H ,10X,76HDWARF MISTLETOE RATING ABOVE WHICH PERIODIC THI
     1NNINGS WILL NOT BE EXECUTED -,F4.1,1H.)
       WRITE (6,240) COMCU,COMBF
  240 FORMAT (1H ,10X,44HMINIMUM CUTS FOR INCLUSION IN TOTAL YIELDS--,F6
     1.0,15H CUBIC FEET AND,F7.0,12H BOARD FEET.)
       GO TO (250,270,290), ICUT
  250 WRITE (6,260)
  260 FORMAT (1H ,10X,35HNO NONCOMMERCIAL THINNINGS ALLOWED.)
       GO TO 310
  270 WRITE (6,280)
  280 FORMAT (1H ,10X,87HPRECOMMERCIAL INITIAL THINNING ALLOWED. NONCOMM
     1ERCIAL SUBSEQUENT THINNINGS NOT ALLOWED.)
      GO TO 310
  290 WRITE (6,300)
  300 FORMAT (1H ,10X,35HALL THINNINGS MAY BE NONCOMMERCIAL.)
  310 II = I + M
      IF(VAR(II) .GT. 0.0 .AND. VAR(II) .LT. VAR(23)) GO TO 330
      II = I + 20
      IF(VAR(II) .LE. 0.0) GO TO 370
      WRITE (6,320) VAR(I),VAR(II)
  320 FORMAT (1H ,10X,14HAT INITIAL AGE,F5.0,1H,,F5.0,57H PERCENT OF THE
     1 TREES WERE INFECTED WITH DWARF MISTLETOE.)
      GO TO 370
  330 WRITE (6,340) VAR(II)
  340 FORMAT (1H ,10X,40HDWARF MISTLETOE INFECTION STARTED AT AGE,F5.0)
  370 IF(KTR(I) .EQ. 0) GO TO 390
      WRITE (6,380)
  380 FORMAT (1H ,10X,52HNOTE THAT NOT ALL SCHEDULED THINNINGS WERE POSS
     1IBLE.)
  390 RETURN
      END
```

```
      SUBROUTINE SWVOL
C
C TO COMPUTE TOTAL CU. FT. AND CONVERT TO MERCH. CU. FT. AND BD. FT.
C
      COMMON /BLKA/BA,DBH,DEN,HT,BDF,CFM,TCF
C
      FCTR = 0.0
      PROD = 0.0
C
C COMPUTE TOTAL CU. FT.
C
      D2H = DBH * DBH * HT
      IF(D2H .GT. 5000.0) GO TO 10
      TCF = (0.53313 + 0.00033 * BA + 0.00173 * D2H) * DEN
      GO TO 20
   10 TCF = (0.00237 * BA + 0.00211 * D2H - 1.09356) * DEN
C
C OBTAIN CONVERSION FACTOR FOR MERCH. CU. FT. - VOLUMES TO 4.0-INCH TOP
C IN TREES 6.0 INCHES D.B.H. AND LARGER.
C
   20 IF(DBH .LT. 5.0) GO TO 70
      IF(DBH .GT. 6.5) GO TO 30
      FCTR = 0.25222 * DBH - 1.01119
      GO TO 50
   30 IF(DBH .GT. 10.0) GO TO 40
      FCTR = 3.02485 - 0.03957 * DBH - 11.35314 / DBH
      GO TO 50
   40 FCTR = 1.03336 - 1.41034 / DBH
C
C OBTAIN CONVERSION FACTOR FOR BD. FT. - VOLUMES TO VARIABLE TOP IN
C TREES 10.0 INCHES D.B.H. AND LARGER.
C
   50 IF(DBH .LT. 8.0) GO TO 70
      IF(DBH .GT. 11.5) GO TO 60
      PROD = 0.0028 * BA + 0.04355 * DBH * DBH - 2.78326
      GO TO 70
   60 PROD = 0.83343 + 0.20531 * DBH
C
C CONVERT TOTAL CU. FT. TO MERCH. CU. FT. AND BD. FT.
C
   70 BDF = TCF * PROD
      CFM = TCF * FCTR
      RETURN
      END
```

```
      SUBROUTINE SWCUT1
C
C TO ESTIMATE CHANGE IN AVERAGE D.B.H. DUE TO PARTIAL CUTTING,
C SOUTHWESTERN PONDEROSA PINE FROM SEL M.
C
      COMMON /BLKB/BAST(2),DBHO(2),DBHT(2),DENO(2),DENT(2),DMR(2),PRET,
     1REST(2),ITM,MOL,DMLEV,IREGN(2),PINF(2),ISANS(2)
C
      I = ITM
      IF(DBHO(I) .LT. 9.5) GO TO 50
C
C COMPUTE D.B.H. IF DBHO IS LARGE ENOUGH FOR BASAL AREA TO REMAIN
C CONSTANT.
C
      PRET = 100.0
      DO 40 KJ=1,100
      IF(PRET .LT. 50.0 .OR. DBHO(I) .LT. 3.0) GO TO 10
      DBHE = 0.73365 + 1.02008 * DBHO(I) - 0.01107 * (PRET - 50.0) -
     1 0.00014 * (PRET - 50.0) * (PRET - 50.0)
      GO TO 15
   10 PDBHE = 0.49401 + 0.71896 * ALOG10(DBHO(I)) - 0.22530 *
     1 ALOG10(PRET) + 0.12615 * ALOG10(DBHO(I)) * ALOG10(PRET)
      DBHE = 10.0 ** PDBHE
   15 IF(IREGN(I) .EQ. 1) GO TO 20
      IF(DMR(I) .LE. 0.0) GO TO 20
      TEM = DBHE - DBHO(I)
      DBHE = DBHO(I) + TEM * 0.5
   20 IDBHE = DBHE  * 10.0 + 0.5
      DBHE = IDBHE
      DBHE = DBHE * 0.1
      DENE = DENO(I) * PRET * 0.01
      NDENE = DENE + 0.5
      DENE = NDENE
      BASE = 0.0054542 * DBHE * DBHE * DENE
      NBASE = BASE * 10.0 + 0.5
      BASE = NBASE
      BASE = BASE * 0.1
      TMPY = 0.0054542 * DBHE * DBHE
      TEM = BASE - REST(I)
      IF(KJ .EQ. 1 .AND. TEM .LT. 0.0) GO TO 190
      IF(TEM .LE. TMPY) GO TO 140
      IF(TEM .LT. 4.0) GO TO 30
      PRET = PRET - 1.0
      GO TO 40
   30 PRET = PRET - 0.3
   40 CONTINUE
      GO TO 140
C
C COMPUTE D.B.H. IF BASAL AREA INCREASES WITH D.B.H.
C
   50 PRET = 40.0
      IF(DBHO(I) .GT. 7.0) PRET = 70.0
      DO 130 J=1,100
      IF(PRET .GE. 50.0 .AND. DBHO(I) .GT. 2.9) GO TO 60
      PDBHE = 0.44401 + 0.71890 * ALOG10(DBHO(I)) - 0.22530 *
     1 ALOG10(PRET) + 0.12616 * ALOG10(DBHO(I)) * ALOG10(PRET)
      DBHE = 10.0 ** PDBHE
      GO TO 65
   60 DBHE = 0.73365 + 1.02008 * DBHO(I) - 0.01107 * (PRET - 50.0) -
     1 0.00014 * (PRET - 50.0) * (PRET - 50.0)
   65 IF(IREGN(I) .EQ. 1) GO TO 70
      IF(DMR(I) .LE. 0.0) GO TO 70
      TEM = DBHE - DBHO(I)
      DBHE = DBHO(I) + TEM * 0.5
   70 IDBHE = DBHE * 10.0 + 0.5
      DBHE = IDBHE
      DBHE = DBHE * 0.1
      DENE = DENO(I) * PRET * 0.01
      NDENE = DENE + 0.5
      DENE = NDENE
      BASE = 0.0054542 * DBHE * DBHE * DENE
      NBASE = BASE * 10.0 + 0.5
      BASE = NBASE
      BASE = BASE * 0.1
      BREAK = 43.0 * REST(I) / 80.0
      IF(BASE .GT. BREAK) GO TO 80
      DBHP = (80.0 / REST(I)) * 0.08682 * BASE + 0.44036
      GO TO 100
   80 BUST = 66.2 * REST(I) / 80.0
      IF(BASE .GT. BUST) GO TO 90
      DBHP = (80.0 / REST(I)) * 0.10938 * BASE - 0.17848
      GO TO 100
   90 TMPY = BASE * 80.0 / REST(I)
      TEM = TMPY * TMPY
      DBHP = 19.34740 * TMPY - 0.25673 * TEM + 0.0012534 * TEM * TMPY
     * - 448.75833
      IF(TMPY .GT. 80.0) DBHP = DBHO(I) + 0.9
  100 IDBHP = DBHP * 10.0 + 0.5
      DBHP = IDBHP
      DBHP = DBHP * 0.1
      IF(DBHP - DBHE) 110,140,120
  110 PRET = PRET * 1.02
      IF(PRET .GT. 100.0) GO TO 190
      GO TO 130
  120 PRET = PRET * 0.98
  130 CONTINUE
  140 DBHT(I) = DBHE
C
C COMPUTE POST-CUTTING BASAL AREA.
C
      IF(DBHT(I) .GT. 2.0) GO TO 145
      SQFT = 6.03633 * DBHT(I)
      GO TO 160
  145 IF(DBHT(I) .GT. 5.0) GO TO 150
      SQFT = 11.58495 * DBHT(I) - 11.09724
      GO TO 160
  150 IF(DBHT(I) .GE. 10.0) GO TO 170
      TEM = DBHT(I) * DBHT(I)
      SQFT = 7.76226 * DBHT(I) + 0.85284 * TEM - 0.07952 * TEM * DBHT(I)
     1 - 3.45624
  160 BAST(I) = (REST(I) / 80.0) * SQFT
      GO TO 180
  170 BAST(I) = REST(I)
  180 RETURN
  190 PRET = 100.0
      RETURN
      END
```

```
      SUBROUTINE SWCUT2
C
C TO ESTIMATE CHANGE IN AVERAGE D.B.H. DUE TO THINNING, SOUTHWESTERN
C PONDEROSA PINE FROM ABOVE.
C
      COMMON /BLKB/BAST(2),DBHO(2),DBHT(2),DENO(2),DENT(2),DMR(2),PRET,
     1REST(2),ITM,MOL,DMLEV,IREGN(2),PINF(2),ISANS(2)
C
      I = ITM
C
C DETERMINE PRET AND D.B.H. AFTER CUTTING BY AN ITERATIVE PROCESS.
C
      ITER = 0
      PRETP = 100.0
      PRET = 50.0
    5 ITER = ITER + 1
      IF(PRET .LT. 50.0 .OR. DBHO(I) .LT. 4.0) GO TO 10
      DBHE = 0.98543 * DBHO(I) + 0.00807 * (PRET - 50.0) + 0.00025 *
     1 (PRET - 50.0) * (PRET - 50.0) - 0.91172
      GO TO 20
   10 PDBHE = 0.51618 * ALOG10(PRET) + 1.69213 * ALOG10(DBHO(I))
     1 - 0.34768 * ALOG10(PRET) * ALOG10(DBHO(I)) - 1.03421
      DBHE = 10.0 ** PDBHE
   20 IF(DMR(I) .LE. 0.0) GO TO 30
      TEM = DBHE - DBHO(I)
      DBHE = DBHO(I) + TEM * 0.5
   30 DENE = DENO(I) * PRET * 0.01
      TREBA = 0.0054542 * DBHE * DBHE
      BASE = TREBA * DENE
      IF(DBHE .GT. 2.0) GO TO 35
      GSLEVL = 80.0 * BASE / (6.03633 * DBHE)
      GO TO 60
   35 IF(DBHE .GT. 4.92687) GO TO 40
      GSLEVL = 80.0 * BASE / (11.58495 * DBHE - 11.09724)
      GO TO 60
   40 IF(DBHE .GT. 10.07636) GO TO 50
      TEM = DBHE * DBHE
      GSLEVL = 80.0 * BASE / (7.76226 * DBHE + 0.85283 * TEM - 0.07952
     1 * TEM * DBHE - 3.45624)
      GO TO 60
   50 GSLEVL = BASE
   60 TEM = GSLEVL - REST(I)
      TEMA = ABS(TEM)
      IF(TEMA .LT. TREBA .OR. TEMA .LT. 0.01) GO TO 80
      IF(ITER .GE. 100) GO TO 80
      DIFF = ABS(PRETP - PRET) * 0.5
      PRETP = PRET
      IF(TEM .GT. 0.0) GO TO 70
      PRET = PRET + DIFF
      GO TO 5
   70 PRET = PRET - DIFF
      GO TO 5
C
C SET POST-CUTTING VALUES.
C
   80 IDBHE = DBHE * 10.0 + 0.5
      DBHE = IDBHE
      DBHT(I) = DBHE * 0.1
      IDENE = DENE + 0.5
      DENT(I) = IDENE
      BAST(I) = 0.0054542 * DBHT(I) * DBHT(I) * DENT(I)
      RETURN
      END
```

APPENDIX 2
Output of Sample Problem

```
                    YIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PINE, STAND NUMBER      1.

                                            SITE INDEX  70
                              THINNING INTENSITY-- INITIAL-  120. SUBSEQUENT-   90.

                    HYPOTHETICAL HEALTHY EVEN-AGED STAND. BEGIN TABLE AT AGE 30.

                CHARACTERISTICS BEFORE AND AFTER THINNING                                 PERIODIC INTERMEDIATE CUTS

 STAND                  BASAL   AVERAGE  AVERAGE   TOTAL   MERCHANT-    SAWTIMBER           BASAL    TOTAL   MERCHANT-    SAWTIMBER
  AGE           TREES   AREA    D.B.H.   HEIGHT   VOLUME  ABLE VOLUME     VOLUME    TREES   AREA    VOLUME  ABLE VOLUME     VOLUME
(YEARS)  DMR     NO.   SQ.FT.    IN.       FT.    CU.FT.     CU.FT.       BD.FT.     NO.   SQ.FT.   CU.FT.     CU.FT.       BD.FT.

   30    0.0     950    119      4.8       25      1530        380            0
   30    0.0     463     79      5.6       26       940        380            0      487     40      590          0             0

   40    0.0     458    109      6.6       35      1520        980            0

   50    0.0     449    134      7.4       44      2200       1660          500
   50    0.0     226     83      8.2       45      1350       1110          500      223     51      850        550             0

   60    0.0     225    104      9.2       51      1870       1640         2200

   70    0.0     223    124     10.1       58      2600       2340         5200
   70    0.0     139     90     10.9       59      1330       1750         5100       84     34      670        590           100

   80    0.0     139    107     11.9       64      2560       2360         8400

   90    0.0     139    124     12.8       69      3220       2990        11200
   90    0.0      89     90     13.6       70      2350       2200         8500       50     34      870        790          2700

  100    0.0      89    103     14.6       74      2890       2730        11100

  110    0.0      89    117     15.5       78      3440       3260        13800
  110    0.0      28     45     17.2       80      1360       1310         6000       61     72     2030       1950          7800

  120    0.0      28     53     18.7       83      1680       1620         7900

  130    0.0      28     62     20.1       86      2010       1950        10000
                                                                 TOTAL YIELDS                      7070       5830         20500
       MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
       BD. FT. - TREES 10.0 INCHES D.B.H. AND LARGER TO VARIABLE TOP LIMIT.
       INITIAL THINNING FROM ABOVE ALLOWED IN STANDS WITH DWARF MISTLETOE.
       DWARF MISTLETOE RATING ABOVE WHICH PERIODIC THINNINGS WILL NOT BE EXECUTED - 3.0.
       MINIMUM CUTS FOR INCLUSION IN TOTAL YIELDS--  320. CUBIC FEET AND  1500. BOARD FEET.
       PRECOMMERCIAL INITIAL THINNING ALLOWED. NONCOMMERCIAL SUBSEQUENT THINNINGS NOT ALLOWED.
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                    YIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PINE, STAND NUMBER      2.

                                            SITE INDEX  70
                              THINNING INTENSITY-- INITIAL-  120. SUBSEQUENT-   90.

                    HYPOTHETICAL EVEN-AGED STAND. INFESTATION STARTS AT AGE 10.

                CHARACTERISTICS BEFORE AND AFTER THINNING                                 PERIODIC INTERMEDIATE CUTS

 STAND                  BASAL   AVERAGE  AVERAGE   TOTAL   MERCHANT-    SAWTIMBER           BASAL    TOTAL   MERCHANT-    SAWTIMBER
  AGE           TREES   AREA    D.B.H.   HEIGHT   VOLUME  ABLE VOLUME     VOLUME    TREES   AREA    VOLUME  ABLE VOLUME     VOLUME
(YEARS)  DMR     NO.   SQ.FT.    IN.       FT.    CU.FT.     CU.FT.       BD.FT.     NO.   SQ.FT.   CU.FT.     CU.FT.       BD.FT.

   30    1.8     950    119      4.8       25      1530          0            0
   30     .6     405     41      4.3       23       530          0            0      545     78     1000          0             0

   40    1.0     403     74      5.8       32      1000        450            0

   50    1.4     399    104      6.9       41      1620       1120            0
   50    1.4     399    104      6.9       41      1620       1120            0        0      0        0          0             0

   60    2.3     353    117      7.8       47      2020       1600            0

   70    3.2     299    121      8.6       54      2310       1960         1800
   70    3.2     299    121      8.6       54      2310       1960         1800        0      0        0          0             0

   80    4.1     242    117      9.4       60      2500       2200         3500

   90    4.9     188    107     10.2       64      2500       2260         5100
   90    4.9     188    107     10.2       64      2500       2260         5100        0      0        0          0             0

  100    5.4     139     92     11.0       69      2310       2100         6300

  110    5.8     101     78     11.9       72      2080       1920         6800
  110    5.0      48     45     13.1       73      1220       1140         4300       53     33      860        780          2500

  120    5.4      36     41     14.5       76      1180       1110         4500

  130    5.7      27     37     15.9       79      1110       1050         4600
                                                                 TOTAL YIELDS                      2970       1830          7100
       MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
       BD. FT. - TREES 10.0 INCHES D.B.H. AND LARGER TO VARIABLE TOP LIMIT.
       INITIAL THINNING FROM ABOVE ALLOWED IN STANDS WITH DWARF MISTLETOE.
       DWARF MISTLETOE RATING ABOVE WHICH PERIODIC THINNINGS WILL NOT BE EXECUTED - 3.0.
       MINIMUM CUTS FOR INCLUSION IN TOTAL YIELDS--  320. CUBIC FEET AND  1500. BOARD FEET.
       PRECOMMERCIAL INITIAL THINNING ALLOWED. NONCOMMERCIAL SUBSEQUENT THINNINGS NOT ALLOWED.
       DWARF MISTLETOE INFECTION STARTED AT AGE  10.
       NOTE THAT NOT ALL SCHEDULED THINNINGS WERE POSSIBLE.
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YIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PINE, STAND NUMBER 3., OVERSTORY.

SITE INDEX 70
THINNING INTENSITY-- INITIAL- 120. SUBSEQUENT- 90.

TWO-STORIED INFESTED STAND WITH IMMEDIATE OVERSTORY REMOVAL.

CHARACTERISTICS BEFORE AND AFTER THINNING									PERIODIC INTERMEDIATE CUTS				
STAND AGE (YEARS)	DMR	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU.FT.	MERCHANTABLE VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.	TREES NO.	BASAL AREA SQ.FT.	TOTAL VOLUME CU.FT.	MERCHANTABLE VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.
150	4.8	20	28	16.1	75	800	760	3300					
								TOTAL YIELDS			800	760	3300

MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
BD. FT. - TREES 10.0 INCHES D.B.H. AND LARGER TO VARIABLE TOP LIMIT.
INITIAL THINNING FROM ABOVE ALLOWED IN STANDS WITH DWARF MISTLETOE.
DWARF MISTLETOE RATING ABOVE WHICH PERIODIC THINNINGS WILL NOT BE EXECUTED - 3.0.
MINIMUM CUTS FOR INCLUSION IN TOTAL YIELDS-- 320. CUBIC FEET AND 1500. BOARD FEET.
PRECOMMERCIAL INITIAL THINNING ALLOWED. NONCOMMERCIAL SUBSEQUENT THINNINGS NOT ALLOWED.

YIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PINE, STAND NUMBER 3., UNDERSTORY.

SITE INDEX 70
THINNING INTENSITY-- INITIAL- 120. SUBSEQUENT- 90.

TWO-STORIED INFESTED STAND WITH IMMEDIATE OVERSTORY REMOVAL.

CHARACTERISTICS BEFORE AND AFTER THINNING									PERIODIC INTERMEDIATE CUTS				
STAND AGE (YEARS)	DMR	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU.FT.	MERCHANTABLE VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.	TREES NO.	BASAL AREA SQ.FT.	TOTAL VOLUME CU.FT.	MERCHANTABLE VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.
30	1.0	500	55	4.1	21	710	0	0					
30	.5	512	42	3.9	20	560	0	0	88	13	150	0	0
40	.9	509	78	5.3	29	1020	330	0					
50	1.4	503	109	6.3	38	1630	940	0					
50	1.4	503	109	6.3	38	1630	940	0	0	0	0	0	0
60	2.3	444	122	7.1	44	2010	1450	0					
70	3.2	375	128	7.9	51	2340	1870	0					
70	3.2	375	128	7.9	51	2340	1870	0	0	0	0	0	0
80	4.0	303	122	8.6	56	2440	2060	1900					
90	4.9	234	110	9.3	61	2420	2120	3100					
90	4.9	234	110	9.3	61	2420	2120	3100	0	0	0	0	0
100	5.3	173	96	10.1	65	2280	2050	4400					
110	5.8	125	81	10.9	69	2040	1860	5300					
110	5.0	56	45	12.1	70	1150	1070	3800	69	36	830	790	1500
120	5.3	43	43	13.5	73	1160	1090	4200					
130	5.7	32	39	14.9	76	1100	1040	4300					
								TOTAL YIELDS			2140	1830	5800

MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
BD. FT. - TREES 10.0 INCHES D.B.H. AND LARGER TO VARIABLE TOP LIMIT.
INITIAL THINNING FROM ABOVE ALLOWED IN STANDS WITH DWARF MISTLETOE.
DWARF MISTLETOE RATING ABOVE WHICH PERIODIC THINNINGS WILL NOT BE EXECUTED - 3.0.
MINIMUM CUTS FOR INCLUSION IN TOTAL YIELDS-- 320. CUBIC FEET AND 1500. BOARD FEET.
PRECOMMERCIAL INITIAL THINNING ALLOWED. NONCOMMERCIAL SUBSEQUENT THINNINGS NOT ALLOWED.
NOTE THAT NOT ALL SCHEDULED THINNINGS WERE POSSIBLE.

YIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PINE, STAND NUMBER 4., OVERSTORY.

SITE INDEX 70
THINNING INTENSITY-- INITIAL- 120. SUBSEQUENT- 90.

TWO-STORIED INFESTED STAND. OVERSTORY REMOVAL DELAYED 20 YEARS.

CHARACTERISTICS BEFORE AND AFTER THINNING									PERIODIC INTERMEDIATE CUTS				
STAND AGE (YEARS)	DMR	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU.FT.	MERCHANT-ABLE VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.	TREES NO.	BASAL AREA SQ.FT.	TOTAL VOLUME CU.FT.	MERCHANT-ABLE VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.
150	4.8	20	28	16.1	75	800	760	3300					
160	5.0	16	26	17.1	77	740	710	3200					
170	5.2	12	21	18.0	79	630	610	2900					
								TOTAL YIELDS			630	610	2900

MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
BD. FT. - TREES 10.0 INCHES D.B.H. AND LARGER TO VARIABLE TOP LIMIT.
INITIAL THINNING FROM ABOVE ALLOWED IN STANDS WITH DWARF MISTLETOE.
DWARF MISTLETOE RATING ABOVE WHICH PERIODIC THINNINGS WILL NOT BE EXECUTED - 3.0.
MINIMUM CUTS FOR INCLUSION IN TOTAL YIELDS-- 320. CUBIC FEET AND 1500. BOARD FEET.
PRECOMMERCIAL INITIAL THINNING ALLOWED. NONCOMMERCIAL SUBSEQUENT THINNINGS NOT ALLOWED.

YIELDS PER ACRE OF SOUTHWESTERN PONDEROSA PINE, STAND NUMBER 4., UNDERSTORY.

SITE INDEX 70
THINNING INTENSITY-- INITIAL- 120. SUBSEQUENT- 90.

TWO-STORIED INFESTED STAND. OVERSTORY REMOVAL DELAYED 20 YEARS.

CHARACTERISTICS BEFORE AND AFTER THINNING									PERIODIC INTERMEDIATE CUTS				
STAND AGE (YEARS)	DMR	TREES NO.	BASAL AREA SQ.FT.	AVERAGE D.B.H. IN.	AVERAGE HEIGHT FT.	TOTAL VOLUME CU.FT.	MERCHANT-ABLE VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.	TREES NO.	BASAL AREA SQ.FT.	TOTAL VOLUME CU.FT.	MERCHANT-ABLE VOLUME CU.FT.	SAWTIMBER VOLUME BD.FT.
30	1.0	600	55	4.1	21	710	0	0					
40	1.5	538	70	4.9	29	980	0	0					
50	2.5	471	83	5.7	38	1300	550	0					
50	1.6	287	44	5.3	36	680	220	0	184	39	620	330	0
60	2.5	253	62	6.7	43	1010	670	0					
70	3.4	213	73	7.9	49	1290	1030	0					
70	3.4	213	73	7.9	49	1290	1030	0	0	0	0	0	0
80	4.2	172	76	9.0	55	1470	1270	1400					
90	5.1	133	74	10.1	60	1590	1430	3000					
90	5.1	133	74	10.1	60	1590	1430	3000	0	0	0	0	0
100	5.5	98	66	11.1	64	1530	1400	4200					
110	5.9	71	58	12.2	67	1430	1320	4800					
110	5.7	50	45	12.9	68	1140	1060	4000	21	13	290	260	800
120	6.0	36	40	14.2	71	1050	990	3900					
130	6.0	26	35	15.6	73	950	910	3900					
								TOTAL YIELDS			1860	1240	3900

MERCH. CU. FT. - TREES 6.0 INCHES D.B.H. AND LARGER TO 4.0-INCH TOP.
BD. FT. - TREES 10.0 INCHES D.B.H. AND LARGER TO VARIABLE TOP LIMIT.
INITIAL THINNING FROM ABOVE ALLOWED IN STANDS WITH DWARF MISTLETOE.
DWARF MISTLETOE RATING ABOVE WHICH PERIODIC THINNINGS WILL NOT BE EXECUTED - 3.0.
MINIMUM CUTS FOR INCLUSION IN TOTAL YIELDS-- 320. CUBIC FEET AND 1500. BOARD FEET.
PRECOMMERCIAL INITIAL THINNING ALLOWED. NONCOMMERCIAL SUBSEQUENT THINNINGS NOT ALLOWED.
NOTE THAT NOT ALL SCHEDULED THINNINGS WERE POSSIBLE.

Myers, Clifford A., Carleton B. Edminster, and Frank G. Hawksworth. 1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Res. Pap. RM-163, 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Presents a procedure for computation of yield tables for ponderosa pines in Arizona and New Mexico. Possible alternatives include: even-aged or two-storied stands, healthy or diseased stands, and managed or unmanaged stand densities. Stand conditions and severity of dwarf mistletoe infestation change with time and in response to intermediate cuttings. Supersedes SWYLD, published in 1972 as USDA For. Serv. Res. Pap. RM-87. A concise user's guide for program SWYLD2 is available as USDA For. Serv. Gen. Tech. Rep. RM-23, 1976.

Keywords: Stand yield tables, timber management, forest management, simulation, *Arceuthobium vaginatum, Pinus ponderosa.*

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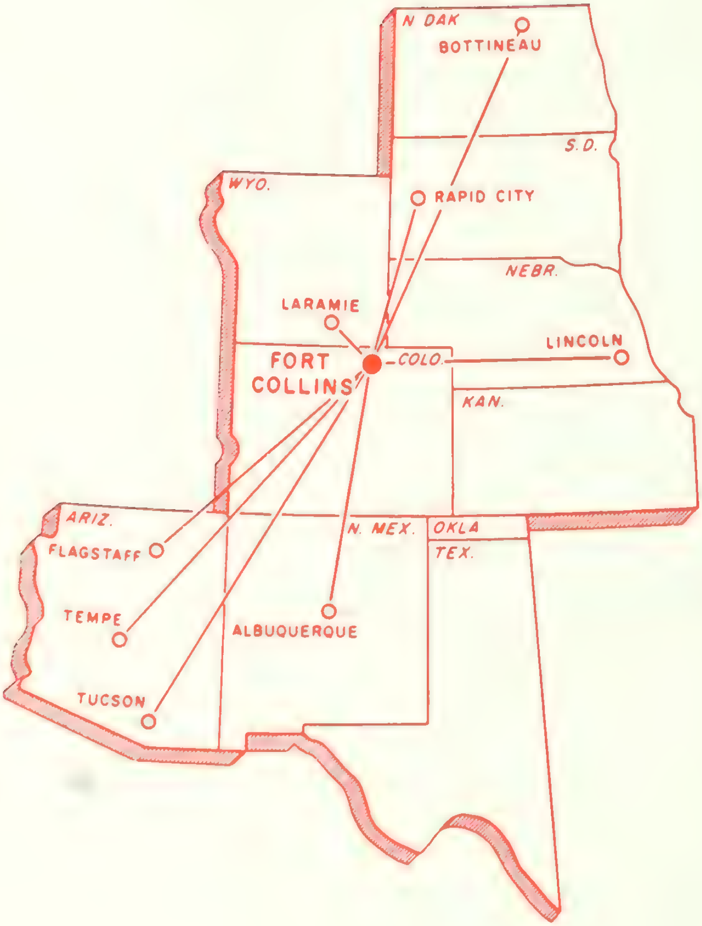
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USDA Forest Service
Research Paper RM-164

March 1976

T. E. Hinds

pen mortality in rocky mountain campgrounds

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Abstract

Hinds, T. E.
1976. Aspen mortality in Rocky Mountain campgrounds. USDA For. Serv. Res. Pap. RM-164, 20 p. Rocky Mt. For and Range Exp. Stn., Fort Collins, Colo.

Aspens die from canker disease infections as a result of mechanical injuries to the live bark inflicted by thoughtless campers. Dead trees usually are cut to reduce camper hazard. Aspen loss is related to campground age. A desirable aspen-type camp unit can be degraded to a treeless site of grass, forbs, and shrubs within 10 to 20 years. The management of aspen campgrounds must be altered if the resource is to be maintained.

Keywords: Recreation use impact, campground degradation, aspen mortality, insects, diseases, *Populus tremuloides.*

About the covers:

Front—A beautiful aspen campsite in Freeman campground, Routt National Forest. Although every tree in the immediate area of the campsite has already been wounded 4 years after campground development, the setting is still natural and attractive.

Back—A once beautiful aspen campsite in the Transfer campground, San Juan National Forest, 14 years after development. All trees in the immediate area of the campsite are dead or have been cut because of disease. The area is no longer attractive to campers.

USDA Forest Service
Research Paper RM-164

March 1976

Aspen Mortality in Rocky Mountain Campgrounds

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[1] Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University.

Contents

Page
Profile of the Campgrounds Studied 2
Study Methods 3
Results 4
Discussion 6
Management Implications 17
Literature Cited 18
Appendix 19
Common and Scientific Names of Diseases, Insects, Plants and Vertebrates mentioned 20

Aspen Mortality in Rocky Mountain Campgrounds

T. E. Hinds

The goal of recreation management is to optimize user satisfaction consistent with certain administrative, budgetary, and resource constraints. To do this, the manager needs to understand the impacts of recreation upon the resource. He must know the character of change to be expected with certain levels and types of use, and how the predicted changes in the physical environment will affect management (Lime and Stankey 1971).

Numerous recreation sites have been developed in aspen stands in the western part of the United States because of their attractiveness and closeness to scenic wonders. General observations by Barker,[2] Hester,[3] and Hinds and Krebill (1975) during the past few years have indicated that aspens in campgrounds have an abnormal incidence of diseases. Accelerated mortality often has resulted in a pronounced reduction in the overall quality of the recreation site (fig. 1). While the cause of aspen decline has never been studied thoroughly, it frequently has been attributed to man-induced trampling, as well as to such natural compounding conditions as poor site, stand age, rotten trees, insects, and successional transition to conifers. Past research has not sufficiently emphasized the response of campground trees to recreation use.

The bark of western aspen[4] is smooth, soft, and living. Because of the fragile nature of its bark, the tree is extremely susceptible to damage, and trunk wounds are quite common (Hinds 1964, Hinds and Krebill 1975). Wounds not only cause physical damage to tree function, but they also are the most common entrance points of canker disease organisms, the most serious cause of tree mortality. Krebill (1972) found that mechanical injury to the trunks of aspen in the Gros Ventre elk winter range in northwestern Wyoming, caused by elk and moose, predisposed the aspen stands to increased disease and accelerated mortality. Aspen stands in campgrounds

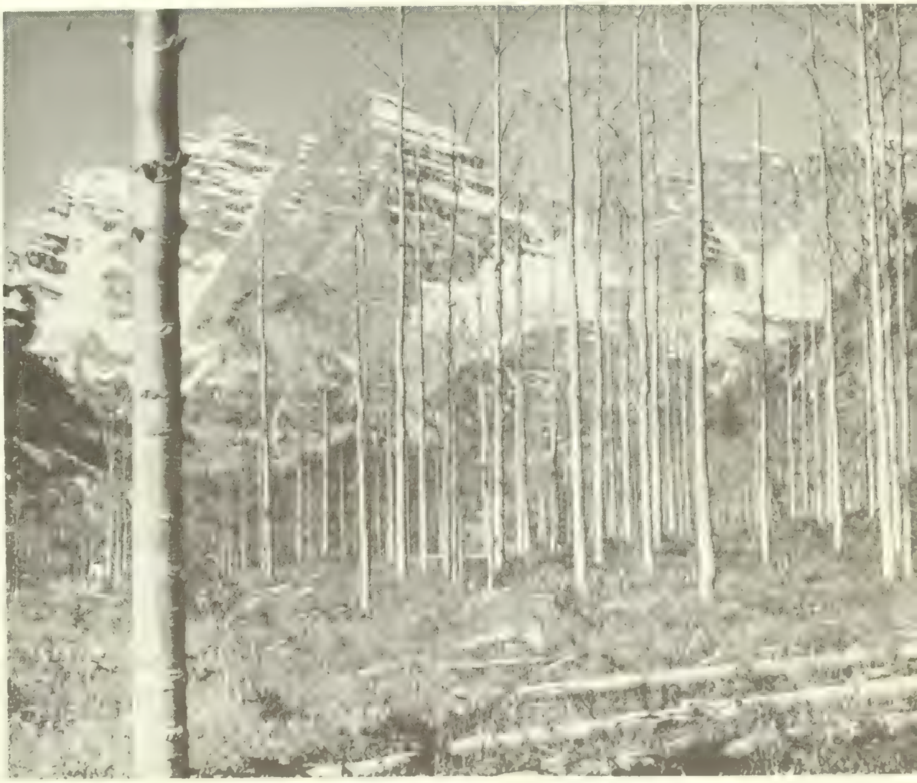

Figure 1.—The lower portion of Maroon Lake campground in July 1973 shows the lack of tree screening between campsites due to dead and down trees. Average camp unit tree loss in this campground has been 68 percent in 12 years.

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[2] *Barker, P. A. 1972. Maintaining and enhancing environmental and aesthetic qualities of intensively used recreation sites, a problem analysis. Research Work Unit FS-INT-1902. (On file at the Intermountain Forest and Range Experiment Station, Logan, Utah.)*

[3] *Memorandum from D. A. Hester, Chief, Branch of Pest Control, to E. J. Grambo, Assistant Regional Forester, August 31, 1966. (On file (No. 5230) at Rocky Mountain Region, Denver, Colorado.)*

[4] *Common and scientific names of diseases, insects, plants, and vertebrates mentioned are found at the end of this Paper.*

likewise are subjected to trunk injury, frequently from the knives, hatchets, and axes that recreationists often carry.

The objective of this study, therefore, was to assess aspen mortality in Colorado campgrounds in relation to trunk injury and the incidence of diseases and insects.

Profile of the Campgrounds Studied

Approximately 350 of the 4,880 public family campgrounds in National Forests are in Colorado. Of these Colorado campgrounds, at least 85 (over 17 percent) are in areas where more than 33 percent of the overstory trees are aspen. Many of the campgrounds were established in the mid-1960's as a result of "Operation Outdoors," a Forest Service program to expand recreational facilities in the National Forests. Most of the campgrounds sampled in this study were established at that time. Some campgrounds developed prior to 1960 also were relocated or rehabilitated as part of that program. Rehabilitation consisted of closing old camp units and establishing new ones in unused portions of an expanded campground. In this analysis, the rehabilitation date was used as the year developed.

The 17 campgrounds examined in this study contain 422 camp units, and are rustic rather than modern. Each camp unit has a table and fireplace fixed in place. Water and sanitation facilities are provided for the campground in general. Most campgrounds sampled are some distance from major highways (fig. 2), insuring that camping—rather than overnight lodging—is the primary use. The physical and recreational data for the 16 Colorado and 1 New Mexico campgrounds used for this study are given in table 1.

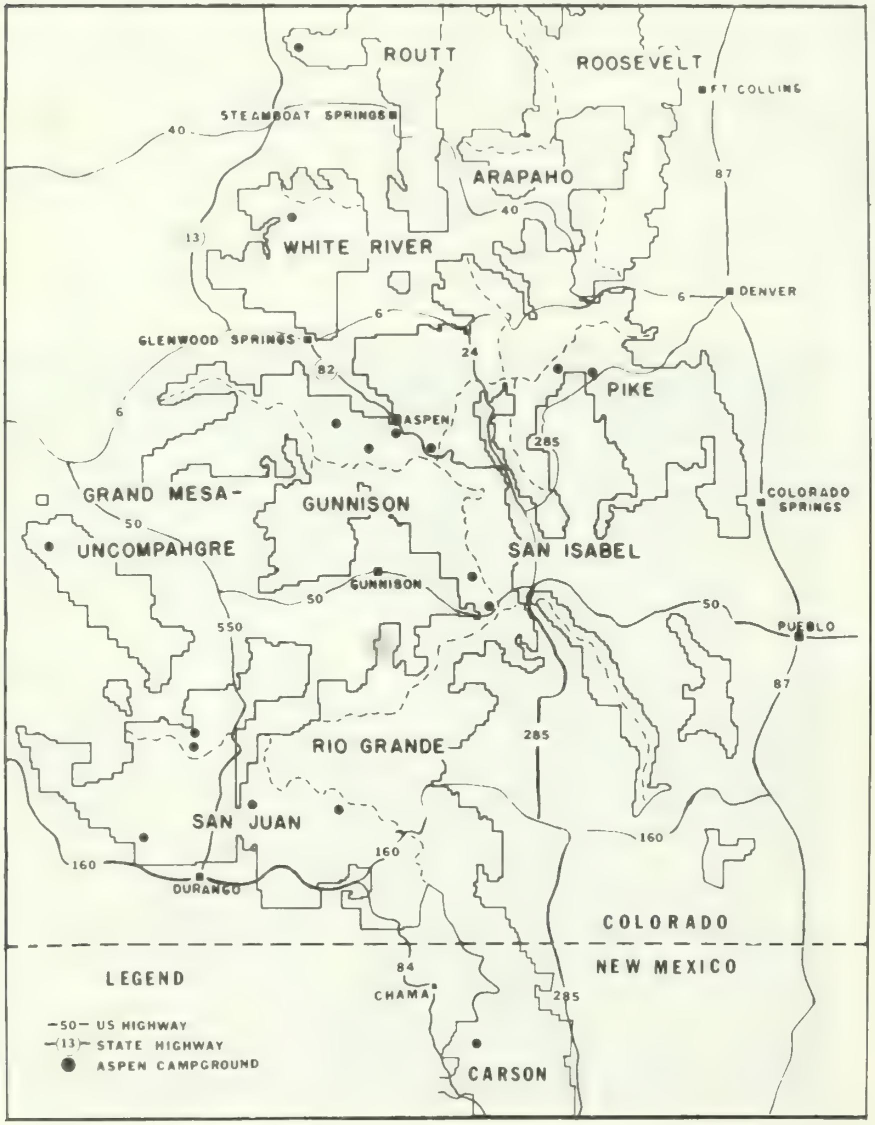


Figure 2.—General locations of aspen campgrounds sampled in Colorado and New Mexico in relation to the major highways.

Table 1.--Physical and recreational data on aspen campgrounds sampled in this study

National Forest and campground	Year developed	Acres	Elevation	Site tree age	Site class	Camp units	Sample plots			People at one time[1]	Days in season	Visitor days 1972	Theoretical capacity[2]
							Interior	Perimeter	Interunit				
		No.	*Feet*	*Years*		*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*Percent*
GRAND MESA-UNCOMPAHGRE NF:													
Divide Fork	1965	6	9,200	93	70	7	2	2	2	45	78	3,400	48
Matterhorn	1966	6	9,500	80	60	23	2	2	2	130	78	22,700	112
Sunshine	1965	8	9,500	107	60	10	2	2	2	60	78	10,900	116
GUNNISON NF:													
Agate	1957	33	9,000	113	50	34	3	3	3	170	93	6,100	19
Snowblind	1965	26	9,800	62	70	23	2	2	2	115	93	8,700	41
PIKE NF:													
Michigan Creek	1964	9	10,000	89	50	13	3	3	3	65	102	4,900	37
Kenosha	1965	16	10,000	87	40	25	3	3	2	125	214	8,000	15
ROUTT NF:													
Freeman	1969	14	8,800	110	40	12	2	2	2	60	86	2,000	19
SAN JUAN NF:													
Cimarrona	1959	12	8,400	99	60	17	3	3	2	85	153	9,600	37
Transfer	1959	7	8,500	80	50	13	2	2	2	65	154	3,100	15
Transfer Park	1954	17	8,600	81	60	25	3	3	3	125	124	6,300	17
WHITE RIVER NF:													
Difficult	1964	11	8,000	84	70	47	5	5	5	259	137	37,200	57
Maroon Lake	1961	47	9,600	91	70	62	7	7	7	340	137	90,600	107
North Fork	1966	55	8,000	71	30	46	4	4	2	235	163	2,800	4
Redstone	1952	24	7,200	66	40	24	3	3	3	120	184	11,700	26
Weller	1964	3	9,200	85	70	11	2	1	1	55	137	7,700	51
CARSON NF:													
Canjilon Lakes	1962	15	9,800	125	50	40	5	5	2	200	100	16,700	42

[1] Number of people a campground is designed to sustain at one time.

[2] A use index, which is the ratio expressed in percent of actual campground occupancy in relation to total number of people the campground is designed to sustain during its open season (1972 basis).

Certain socioeconomic ramifications are associated with these aspen campgrounds. A monetary value of $2 per visitor day has been assigned as the social benefit derived from camping (U.S. Water Resources Council 1973). If we accept this estimate of value, the social benefits derived from Colorado campgrounds in the aspen type alone amount to over $1.5 million per year. The social benefit values of campgrounds in this study amounted to over $500,000 in 1972, or an average of $1,500 per acre. This value is somewhat greater than the $1,200 per acre of development that Barker[2] derived for the public recreation sites on the National Forests in the Intermountain West. The social benefit value of a campground like Maroon Lake campground, for example, with its 90,600 visitor days amounted to $181,200; $3,855 on a per-acre basis; or $2,876 per camp unit in 1972.

Most campgrounds in this study were maintained under the campground fee system used in 1973. Due to site deterioration, fees were not charged at three of the campgrounds and their future closure was anticipated. The camping area of two others was confined. A timber sale to remove 50 cords of firewood was in progress in one; the other was partially closed for lack of funds for proper maintenance, that is, dead tree removal. At today's replacement cost of $4,500 per camp unit, it would cost nearly $2 million to replace the campgrounds examined in this study.

Providing recreationists with sustained satisfaction as well as protecting the investment and the natural environment in these aspen campgrounds should be of considerable importance.

Study Methods

Only campgrounds in which aspen was the predominant type (overstory more than 66 percent aspen) were studied. Campgrounds were selected so that they would be distributed throughout Colorado, and could be sampled in 1 year (1973). The sample also included one campground in northern New Mexico. Although campgrounds often contained both family camp units and family picnic units, only the camp units were sampled. Beginning with the first unit in a campground, every fifth or tenth unit was examined until a minimum of 10 percent of the camp units were sampled. Three types of temporary plots were established:

1. **An Interior Plot,** used to determine the condition of the trees within a camp unit, consisted of a 0.05-acre circular plot (26-foot 4-inch radius) with the center located midway between the fire pit and the picnic table. All trees over 3.0 inches in diameter at breast height (d.b.h.) were described. The number and apparent cause for dead or down trees, and the diameter of stumps were recorded. Saplings 1.0 to 2.9 inches d.b.h. were counted.

2. **A Perimeter Plot,** to determine the condition of trees surrounding the immediate camp unit, was established to supplement the interior plot. The perimeter plot size was variable; that is, size was determined by the height of the tallest tree on the perimeter of the campsite which conceivably could fall into the campsite area. The perimeter plot radius, determined by adding the height of the tallest tree to the radius of the interior plot, was measured from the same center point used for the interior plot. Only overstory tree data describing the live, dead, or cut trees over 5 inches d.b.h., insect attack, cankers, or other diseases were taken. Saplings were not counted.

3. **An Inter-Unit Plot,** to determine the condition of trees which provide a screening effect between camp units, was established midway between the interior plot and an adjacent camp unit. Plot size and information recorded were the same as for the interior plot.

Campground information was obtained from Forest Service RIM sources (Recreation Information Management System, James 1971). Dominant tree height and ages were taken to determine site class of the campground in general. Jones' (1966) aspen site index was used for site comparisons. Tree vigor was rated as normal or poor. Thin crowns, small leaves, and poor growth typified poor vigor.

Bark injury associated with wood-boring insects was noted. A number of species of beetles, mainly roundheaded borers (Cerambycidae) and flatheaded borers (Buprestidae), are known to cause bark injury. Common borers from the Rocky Mountains include the poplar borer, the poplar butt borer, and the bronze birch borer. No attempt was made to distinguish which borer was involved or the frequency of infestation on the trees examined. The presence of these insects was noted only on the basis of external evidence.

Results

Within the 17 campgrounds, there were 422 camp units. A total of 53 interior, 52 perimeter, and 45 inter-unit temporary plots were established at camp units. The average campground age was 11 years; the interior plots averaged 12 live trees and 6 dead trees and/or stumps. The number of live trees and associated damage, and tree loss and cause in the individual campgrounds are summarized in table 2 (see details in the appendix).

Table 2.--Live aspen and aspen losses found in the campground plots, and percentages of common anomalies associated with them

Common anomalies	Interior plots		Perimeter plots		Inter-unit plots	
	No.	*%*	*No.*	*%*	*No.*	[illegible]
LIVE TREES:	636		3,571		666	
With mechanical injuries		83		--		19
With canker infections:		47		5		14
Ceratocystis		29		2		8
Cytospora		10		1		4
Cenangium		5		1		1
Cryptosphaeria		2		1		1
Hypoxylon		1		<1		<1
Trunk over half girdled by canker infections		22		2		6
Phellinus tremulae[1] conks		6		1		5
Wood borer infestation		18		<1		5
TREE LOSS:	331		1,303		283	
Cut or down		28		21		19
Dead standing		6		6		11
with cankers--		98		94		93
Cytospora		50		42		57
Cenangium		35		47		30
Cryptosphaeria		8		4		4
Ceratocystis		5		1		2
Hypoxylon		0		1		1

[1] *P. tremulae* = *Fomes igniarius* var. *populinus* (Neu.) Campb.

Mechanical injuries to the trunks were found on at least half of the aspens in all interior plots, on at least 75 percent of the trees in 12 of the 17 campgrounds, and on all of the trees in 4 campgrounds. Single and multiple injuries, all apparently done since campground construction, extended from groundline up to 10 feet on the trunk (fig. 3). Although injuries were found on all sides of the tree trunks, a high proportion of them were on the side facing the plot center. All are potential entry points for insects, canker, and other disease organisms which could be fatal to the host tree.

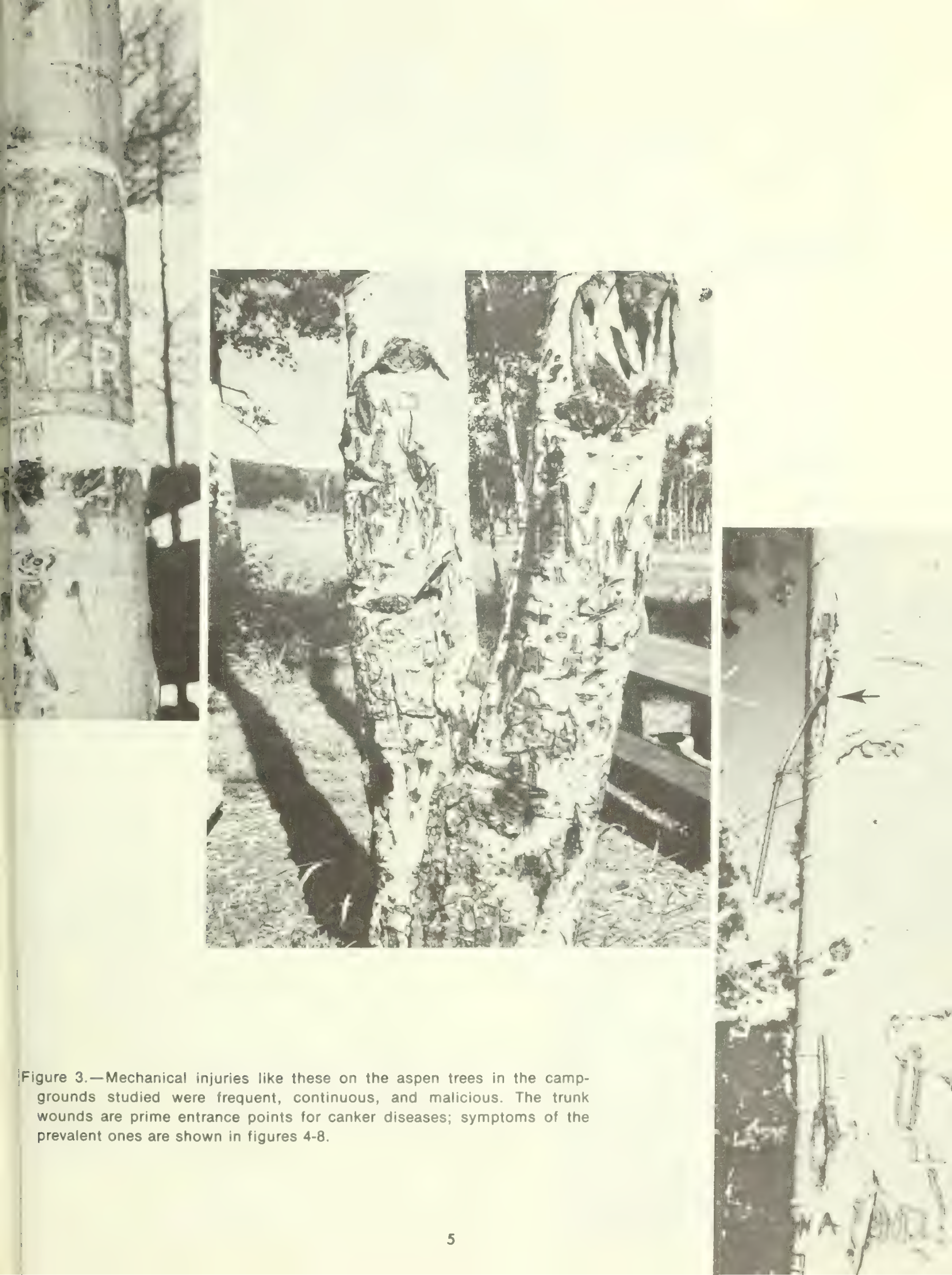


Figure 3.—Mechanical injuries like these on the aspen trees in the campgrounds studied were frequent, continuous, and malicious. The trunk wounds are prime entrance points for canker diseases; symptoms of the prevalent ones are shown in figures 4-8.

Cankers were more common on live trees in the interior plots than in the other plots. Of the interior-plot trees, Ceratocystis canker (fig. 4) was found on 29 percent; Cytospora (fig. 5) on 10 percent; Cenangium (fig. 6) on 5 percent; Cryptosphaeria (fig. 7) on 2 percent; and Hypoxylon (fig. 8) on 1 percent.

Although 66 percent of the original stems over 3.0 inches in diameter on the interior plots are still living, one-third are infected with canker diseases that already have girdled more than half of the trunk circumference. Only time will tell how long these infected trees will survive, but surely no longer than 10 years.

Conks of the false tinder fungus, *Phellinus tremulae* (fig. 9), indicating extensive heart rot (Hinds 1963), were found in camp units of 15 of the 17 campgrounds. Fruiting bodies of other decay fungi were found on less than 1 percent of the trees. The artist's conk, *Ganoderma applanatum,* scaly Pholiota, *Pholiota squarrosa,* and the honey mushroom, *Armillariella mellea,* were the ones encountered. As is typical of these root and butt rot fungi, the fruiting bodies were found at the base of the trees. Such diseased trees are subject to windthrow at any time.

The incidence of borer attack on interior-plot aspens was 3½ times greater than on the inter-unit plots, and 18 times greater than on the perimeter plots, which had the least tree mortality.

Dead trees are cut in campgrounds as standard procedure for hazard control. Some are cut by campers for firewood. Stumps of these cut trees, which remain intact for several years, are a graphic record of aspen loss and subsequent degradation of the campsite (fig. 10). Of the 34 percent tree loss on the interior plots, 28 percent had been cut, while 6 percent were dead and still standing. Assuming that all standing dead or otherwise hazardous trees were removed for camper safety during campground development, the average rate of tree loss in the interior plots has been 3.6 ± 1.0 percent per year (fig. 11) and 2.8 ± 0.7 percent per year for all plots combined (95 percent confidence level) since campground construction.

Other factors such as sunscald, snow damage, insects, and wind contribute to aspen loss; however, canker-caused mortality appears to be the greatest factor. About 95 percent of the dead standing aspens in the three plot areas were killed by cankers (see table 2).

Stand age of the campgrounds varied from 62 to 125 years. Interior-plot tree loss decreased with stand age from 44 percent in the 60- to 80-year age class to 30 percent in stands over 100 years old.

Over half of the campgrounds studied were on good to fair sites; that is, site class 60 or better. Interior-plot tree loss amounted to 33 percent on site class 70, 39 percent on site class 60, 50 percent on site class 50, 43 percent on site class 40, and 20 percent on site class 30.

Half of all trees rated as having poor vigor were suppressed. Vigor was poor for 29 percent of the trees on the interior plots in contrast to 17 percent on the inter-unit plots. On the interior plots, 80 percent of the poor-vigor trees had trunk wounds, 56 percent were cankered, and 21 percent were infested with borers.

Aspen saplings were found on 57 percent of the interior plots, but averaged only four per plot. Saplings were found on 61 percent of the inter-unit plots, and averaged 11 per plot. Other tree species larger than 5.0 inches d.b.h. constituted only 3.8 percent of the total number of trees observed, and were omitted from the analysis.

Discussion

In view of the aspen losses found in this study, managers of recreation sites must recognize that recreationists increase aspen mortality. The devastating role of insects and diseases will increase as trees in these public campgrounds grow older. Aspen mortality observed in this study was due largely to diseases and, to a much lesser degree, borer infestations—but these were secondary causes. The primary cause was mechanical injury to the trunks which, by damaging the bark, predisposed the trees to invasion by virulent plant pathogens.

Mechanical injury can be characterized as deliberate cuts in the bark apparently inflicted with knives, hatchets, and axes. Such vandalism was of a magnitude to be considered of epidemic seriousness. Unless this vandalism is curtailed, a principal value that attracts recreationists to these campgrounds, namely the tree cover, will disappear due to the user's own maliciousness, negligence, and/or ignorance (fig. 12).

Although tree mortality in western aspen campgrounds has been attributed to several causes, the problem has had very little comprehensive study. A study by Beardsley and Wagar (1971) of the Sunrise campground in northern Utah reported that mortality and windthrow did not seem to increase among trees on their study plots following the first 4 years after construction. I observed the Sunrise campground in 1974, 10 years after construction, and found aspen deterioration similar to that in Colorado and New Mexico. At 3 aspen camp units in the campground, 95 percent of the 65 live trees had mechanical injuries, 68 percent had cankers, 32 percent were more than half girdled by the cankers, 25 percent had borer damage, 1 tree was dead, and 30 had been cut since campground construction. The incidence of Cenangium canker appeared to be increasing rapidly throughout the campground (see fig. 6).

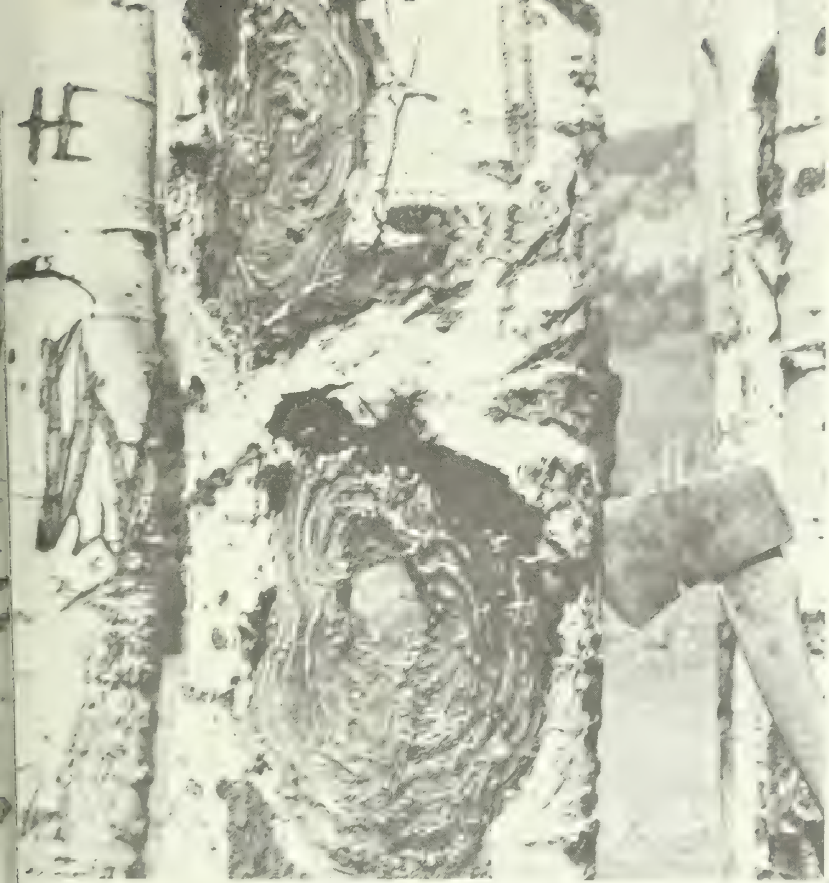
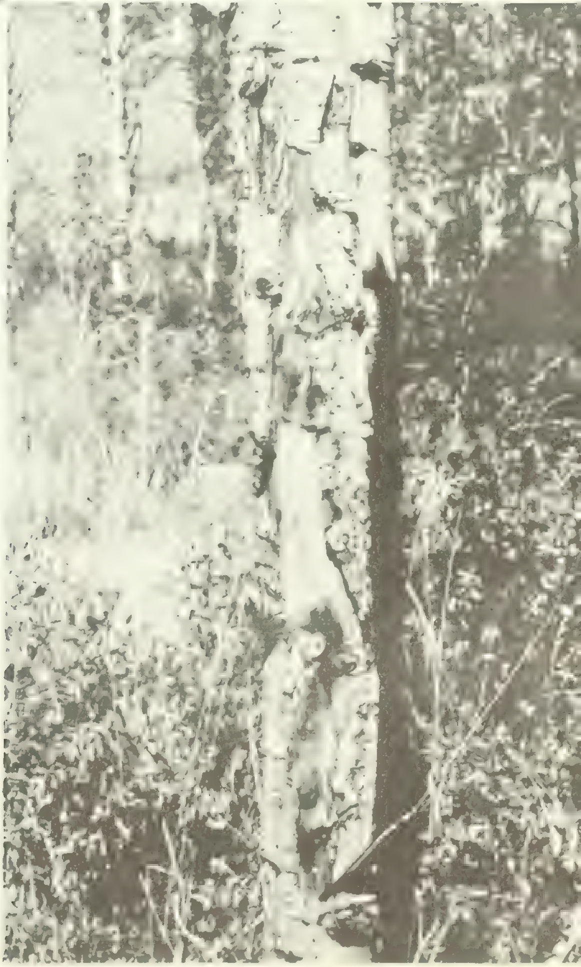


Figure 4.—Ceratocystis cankers initiated at 12-year-old injury, presumably ax inflicted. Many Ceratocystis-infected trunk wounds do not exhibit this typical target-shaped canker.

Figure 5.—Cytospora canker approximately 4 years old continues to spread on this weakened stem.



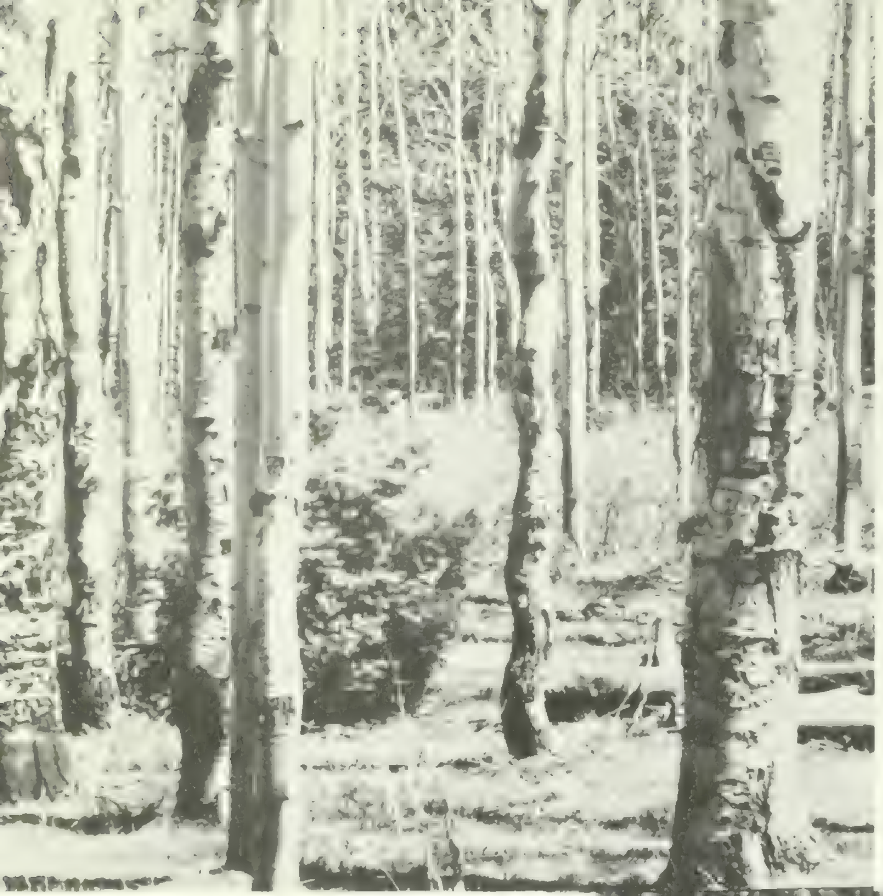


Figure 6.—Cenangium canker has girdled 5 of these trees within 6 years at Sunrise Campground in northern Utah, a campground observed as an auxiliary to the campgrounds of the study.

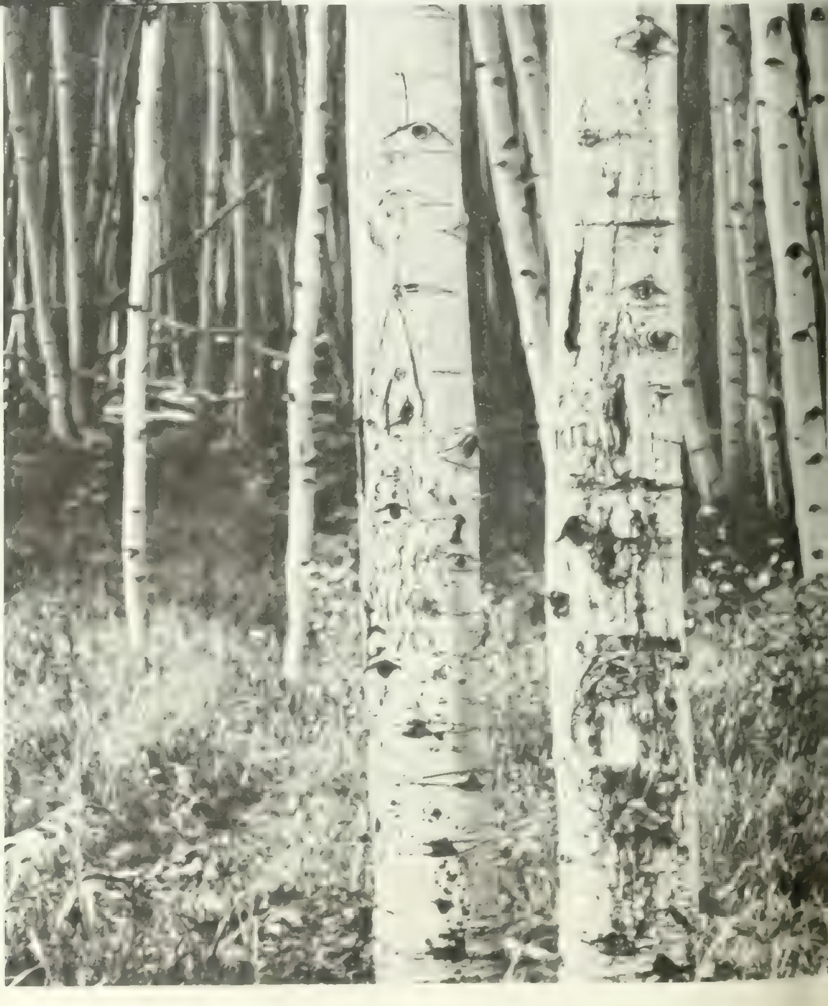


Figure 7.—Cryptosphaeria cankers on 12-inch aspen estimated to be 5 or 6 years old. They appear to have been initiated as camper-caused trunk wounds.

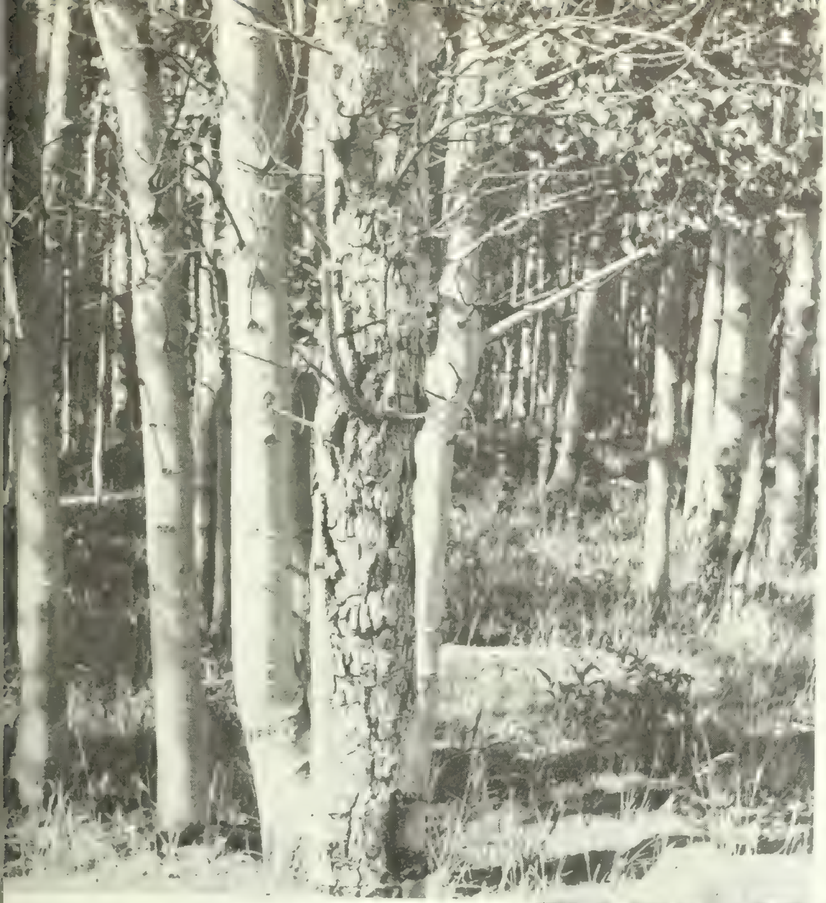


Figure 8.—Aspen two-thirds girdled by Hypoxylon canker in approximately 8 years.

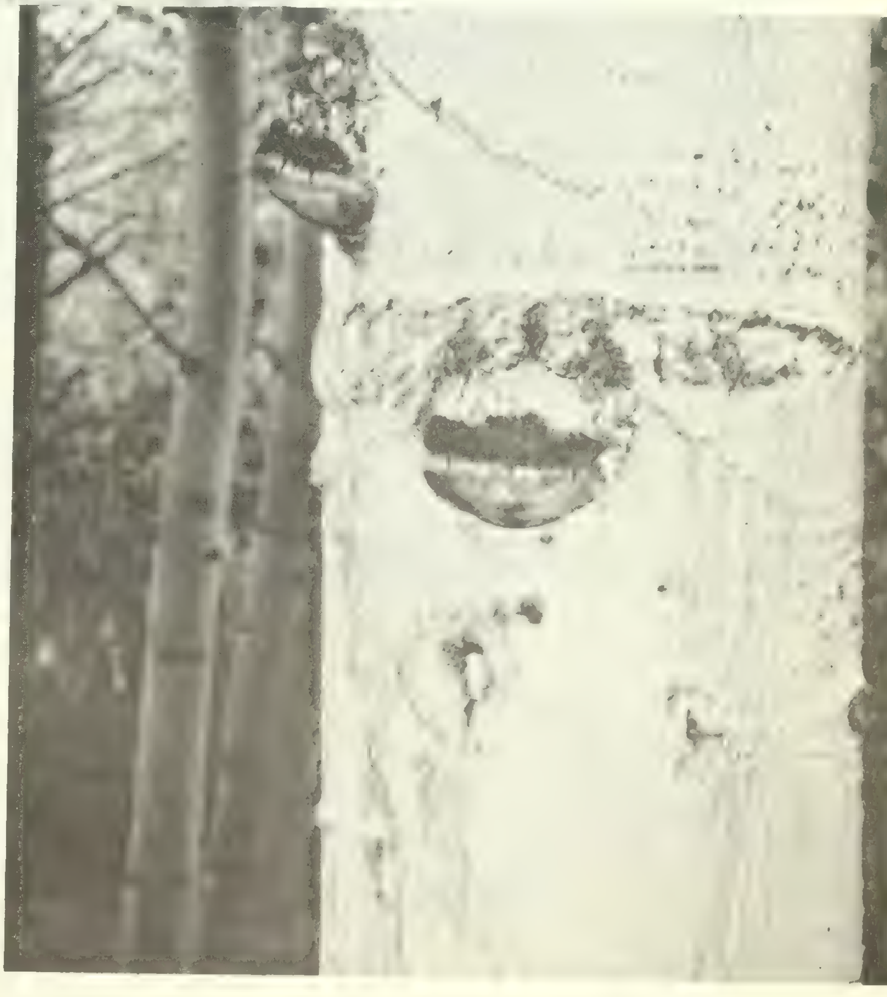


Figure 9.—Hooflike conks of *Phellinus* emanating from old branch stubs. Although infection can occur at trunk wounds, conks usually indicate extensive heart rot that originated many years ago.

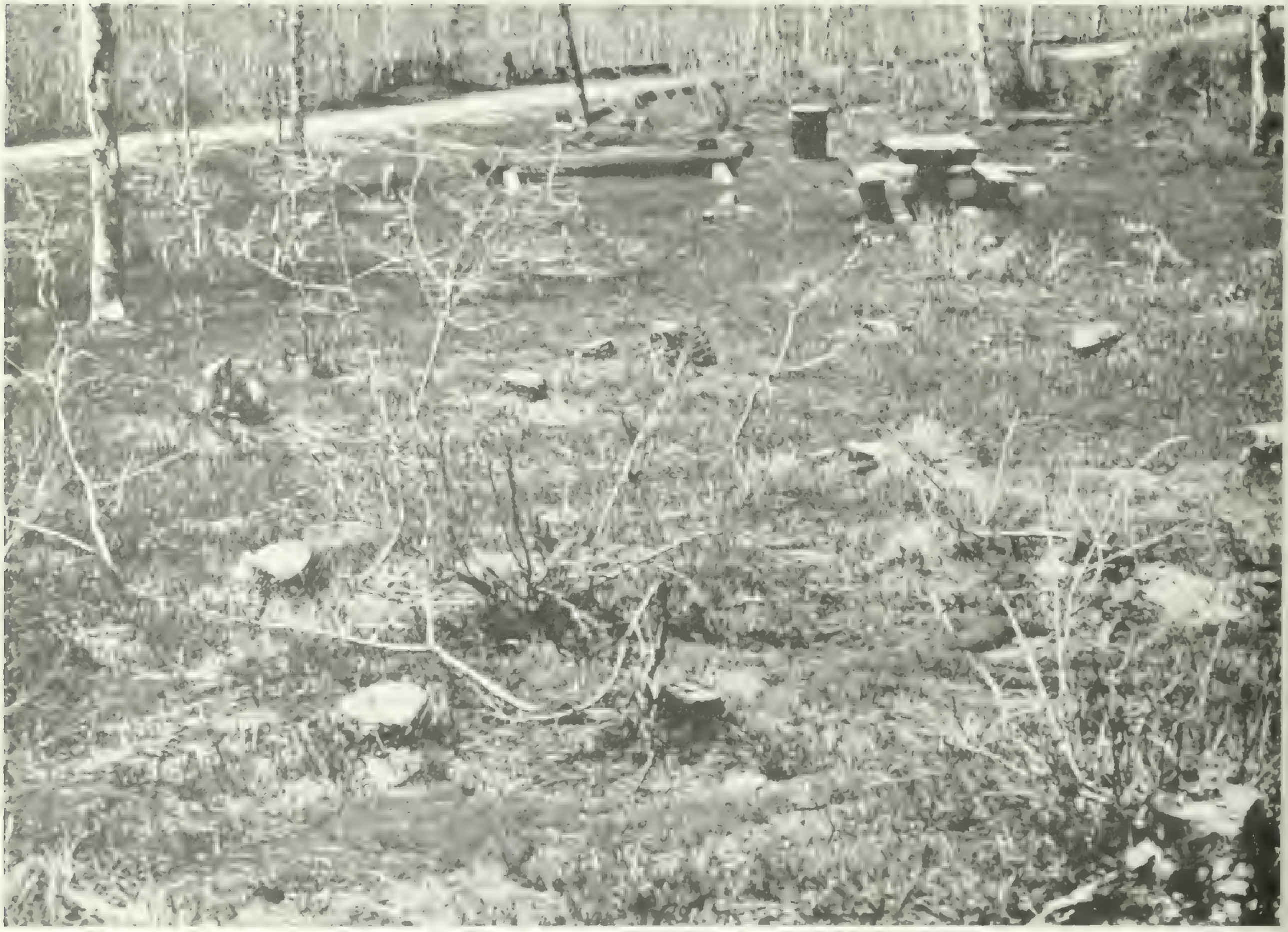


Figure 10.—Tree stumps are visible in early June at Transfer campground. They remain hidden by tall grasses and leafy shrubs during the summer months as seen in figure 18 (top).

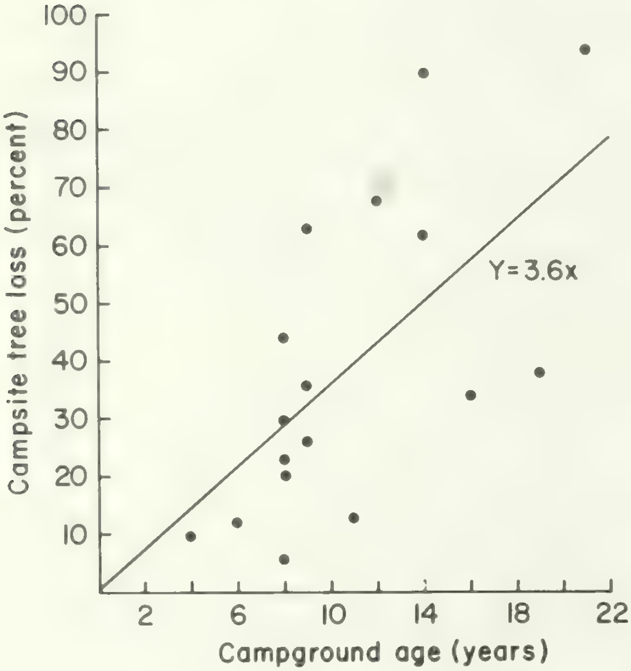


Figure 11.—Relationship between average tree loss in the interior plots and campground age, based on 53 camp units in 17 aspen campgrounds.

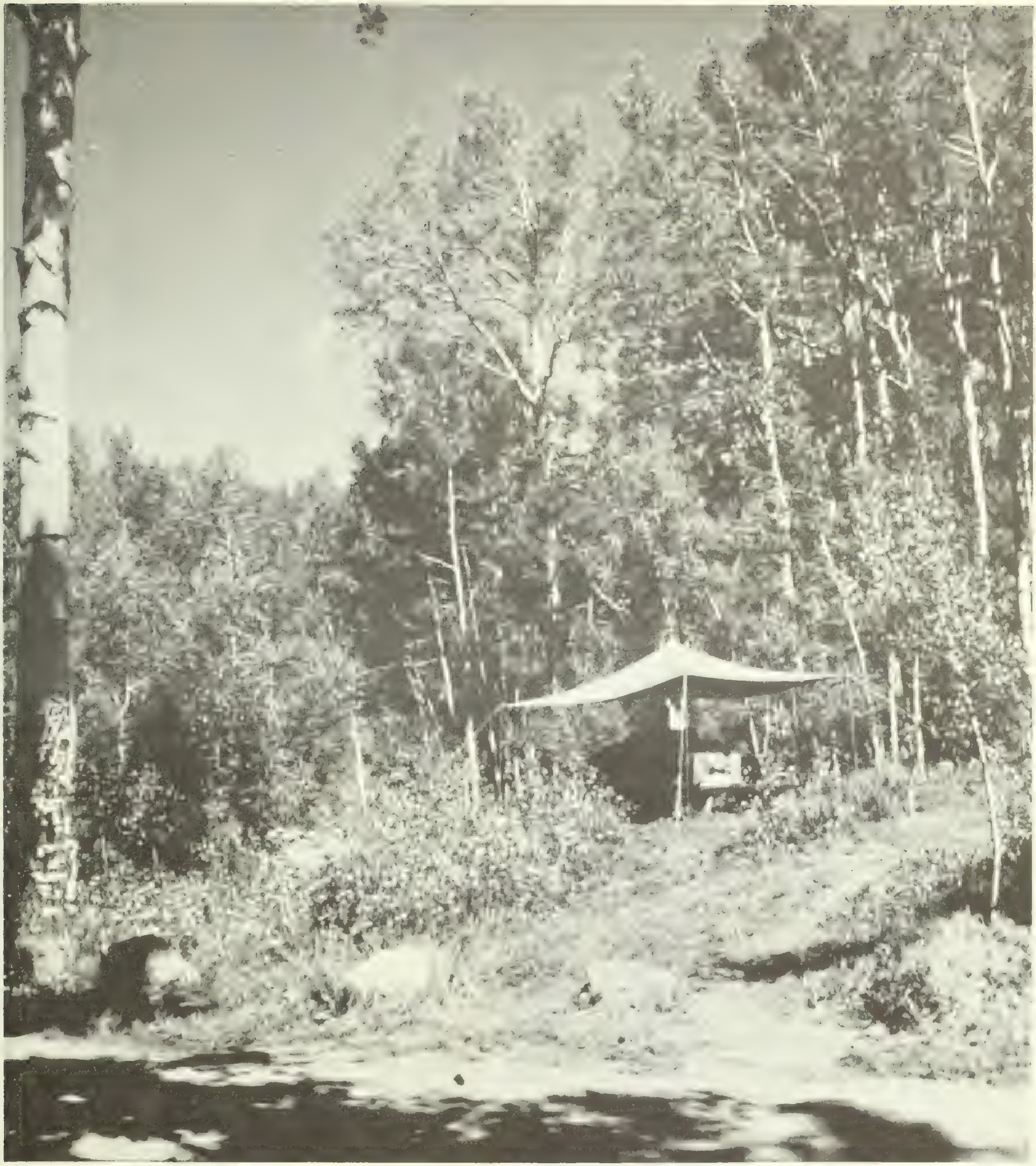


Figure 12.—Sunshine campground, Colorado, Unit 1, with no live trees on campsite. Average diameter of four stumps on the site was 16.6 inches, comparable to the trees in the background. The perimeter plot (90-ft 4-inch radius) had 66 large living trees, 20 cut, and 1 dead standing. Dining tarps for shade will be common on such sites in the future. Average campsite tree loss in this campground is 44 percent in 8 years.

Trampling, poor site, stand age, rotten trees, insects, and the natural successional transition to conifers may all contribute to tree mortality. The most important and fundamental factor, however, seems to be trunk wounding by the campground user. Aspen sites usually support a luxuriant understory of grasses, shrubs, and forbs (Paulsen 1969). Although quantitative information concerning the undergrowth was not taken, casual observations during this study indicate that growth of grasses and shrubs increased when trees were removed (see figs. 15-19). These observations tend to support findings by Beardsley and Wagar (1971) that the effects of trampling on ground-cover vegetation is not as serious in the aspen as in the coniferous types.

There is a rule of thumb among resource managers that 20 to 40 percent of theoretical capacity is the optimum campground usage. In this study, nine campgrounds had less than 40 percent usage in 1972. Tree loss on interior plots averaged 48 percent in 12 years. The remaining eight campgrounds had an average usage of 72 percent and interior-plot tree loss of 30 percent in 9 years. Campground use in the early days of the older campgrounds is unknown. Usage, however, was probably great enough that considerable tree wounding occurred and subsequent tree mortality was high over the years.

While there may be a relationship between site class and tree mortality, no definite conclusions can be drawn from this study due to the numerous site classes involved and the small number of samples examined for each site class. Healthy vigorous aspen stands over 100 years old are not uncommon in the West. While high tree mortality is normal in younger stands due to overcrowding, other factors made mortality abnormally higher in campgrounds. Small trees with thin bark usually had more trunk wounds penetrating into the cambium layer than larger, older trees with their thicker bark. This difference in bark thickness, ease of bark wounding, and subsequent infection of trunk injuries predisposes younger trees to a faster rate of mortality than the older ones.

Rot in Colorado aspen stands under 100 years old usually is not serious; decay may amount to 4 to 13 percent of the gross cubic foot volume (Davidson et al. 1959). The major trunk rot is caused by *Phellinus tremulae. Ganoderma applanatum* causes a butt and root rot which predisposes a tree to windthrow. Both fungi are widespread. In a study of natural stands in western Colorado, Hinds (1964) found that 6 percent of the trees had *P. tremulae* and 0.2 percent had *G. applanatum* conks. In the present study, 6 percent of the trees in the interior plots had *P. tremulae* conks and 0.3 percent had *G. applanatum*—essentially no difference between the two studies. Because decay progresses fairly slowly, most of the aspens showing signs of decay were no doubt infected when the campgrounds were constructed, and decay to date is probably no greater than that found in natural stands.

Insects and diseases may defoliate aspen stands. They usually are not persistent enough over the years to cause tree mortality, however. Persistent wood borer infestations, on the other hand, are common. Aspen decline and mortality caused by borers has not been studied in western aspen. Evidence of trunk damage by a single agrilus larva (fig. 13) indicates that numerous attacks would cause substantial cambium damage. After repeated heavy attacks by the poplar borer, brood trees (fig. 14) remain alive, but the large, oval-shaped tunnels in the trunk make the tree susceptible to wind breakage and serve as openings for the introduction of various rots and canker fungi. Borer infestations tend to vary directly with stem diameter and inversely with density of stocking (Ewan 1960). In this study, the removal of trees at camp units reduced the stand density, which may have promoted an increase in borer infestation. The role that wood borers play in campground tree mortality remains unknown.

As very few other tree species were found on the camp units, it appears that a natural successional transition to conifers is not taking place.

The following comparison of the incidence of stand and tree characteristics found on the interior plots and 4,075 trees examined in 31 natural stands (Hinds 1964) indicates the damage trends in the camp units.

	Natural stands	**Interior plots**
	(Percent)	
Stand basis:		
Live trees	91	66
Standing dead trees	9	6
Cut or down trees	(no record)	28
Live-tree basis:		
With trunk wounds	2	83
With trunk cankers:	11	47
Ceratocystis	4	29
Cytospora	4	10
Cenangium	2	5
Cryptosphaeria	(no record)	2
Hypoxylon	<1	1
With borer damage	3	18

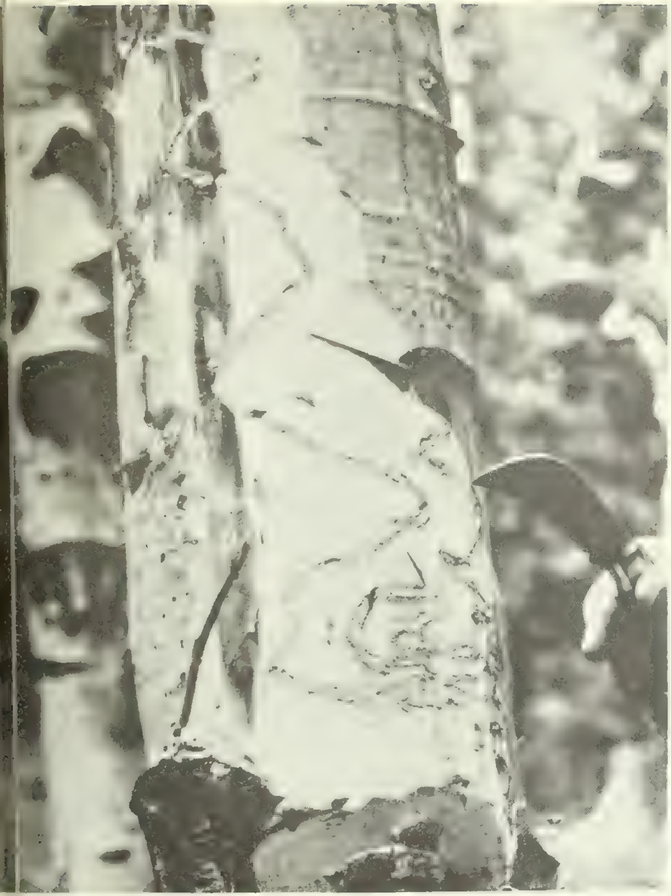


Figure 13.—Bark stripped off a portion of an aspen trunk reveals zigzag tunnels between the phloem and wood that mark an infestation of a single aspen agrilus larva.

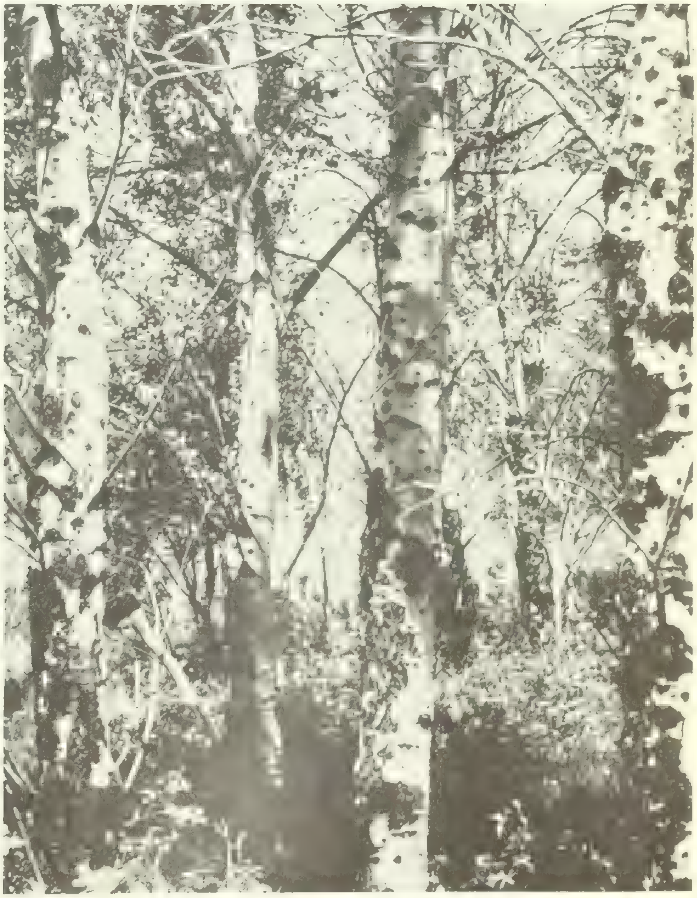


Figure 14.—External evidence of borer damage on aspen: rough, black, bark spots over the location of healed egg niches, and sap flow from exit holes.

An aspen site begins to deteriorate the day a road opens up the area. Tree removal during road building causes trunk wounds, not only on the lower portion of the boles but also in the treetops. The stand canopy is opened and trees along the new road soon begin to suffer from sunscald, wood borers, and wound-infecting fungi. Campsite construction follows a similar pattern. Tree removal during site preparation causes further canopy opening and additional trunk wounds.

Trees on the campsite soon become weakened by thoughtless campers carving on the smooth aspen bark (fig. 15). These wounds become infected, and trees often die within 5 to 10 years. As the trees die and are removed, the stand becomes more open (fig. 16) creating ideal conditions for insect borers and more sunscald (fig. 17). Overall tree vigor declines, mortality increases, and the site is nearly barren of aspen in 10 to 15 years (fig. 18). The reproduction has disappeared—used up for tent pegs, and weiner, marshmallow, and kabob sticks.

Tree wounding and eventual mortality spread outward from the immediate perimeter of the camp unit, until even the trees once used for screening purposes between sites are lost (see figs. 1, 18). Shrubs and forbs multiply because of the reduced competition from overstory vegetation, and lack of trampling by campers who find treeless campsites objectionable. Overall campground deterioration is completed in 25 to 30 years (fig. 19). Campsite recreation cannot be considered as a nonconsumptive use, and the optimum campground usage in aspen campgrounds may well be zero for the sake of the aspen.

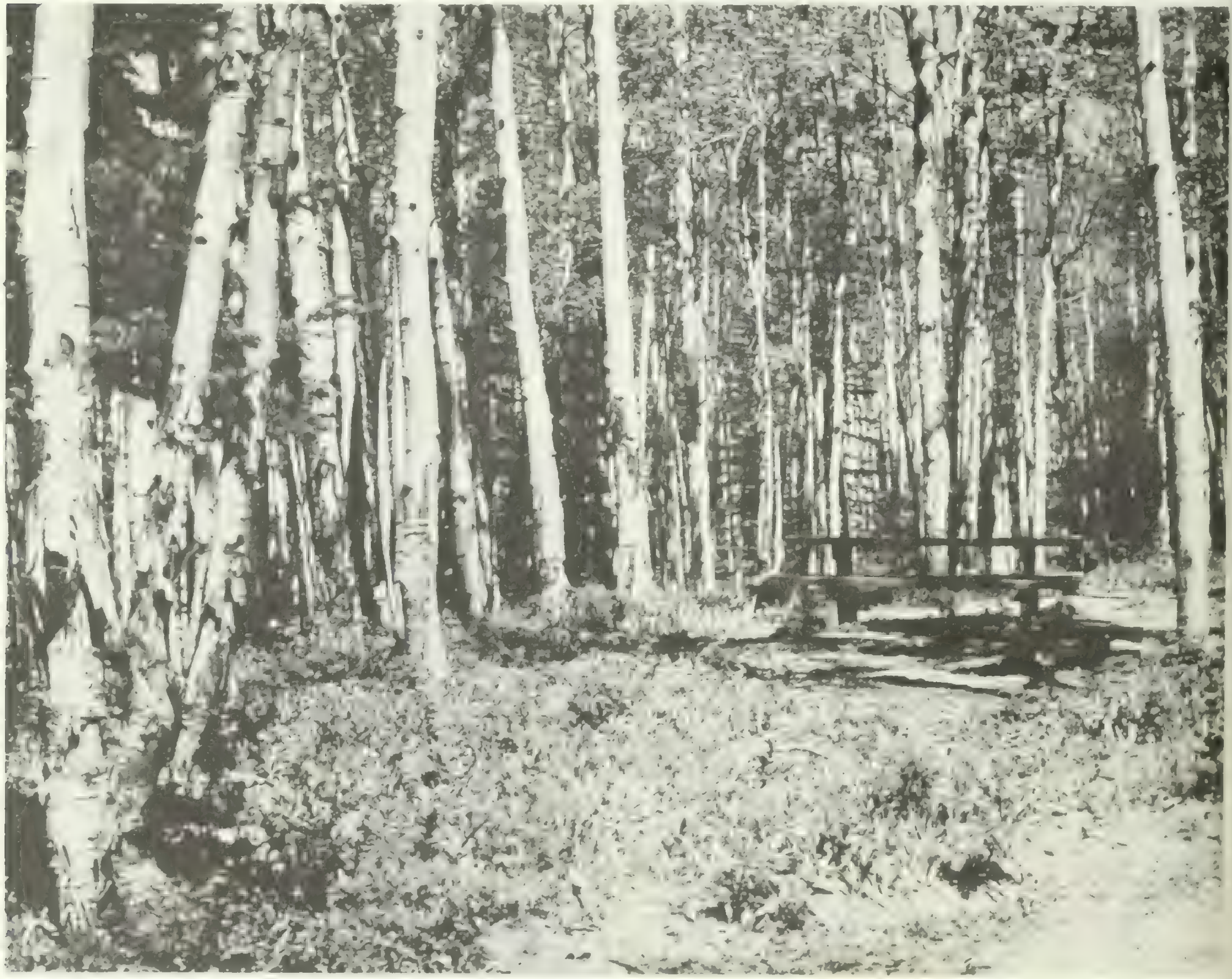


Figure 15.—Freeman campground, Unit 6 interior plot, with 16 live trees: all are wounded, 10 cankered, and 7 over half girdled. Present tree loss is two cut and one dead standing (girdled by Cenangium canker). Perimeter plot (71-ft 4-inch radius) has 84 live trees plus 6 cankered, dead standing, and 1 cut. Average camp unit tree loss in this campground is 10 percent in 4 years.

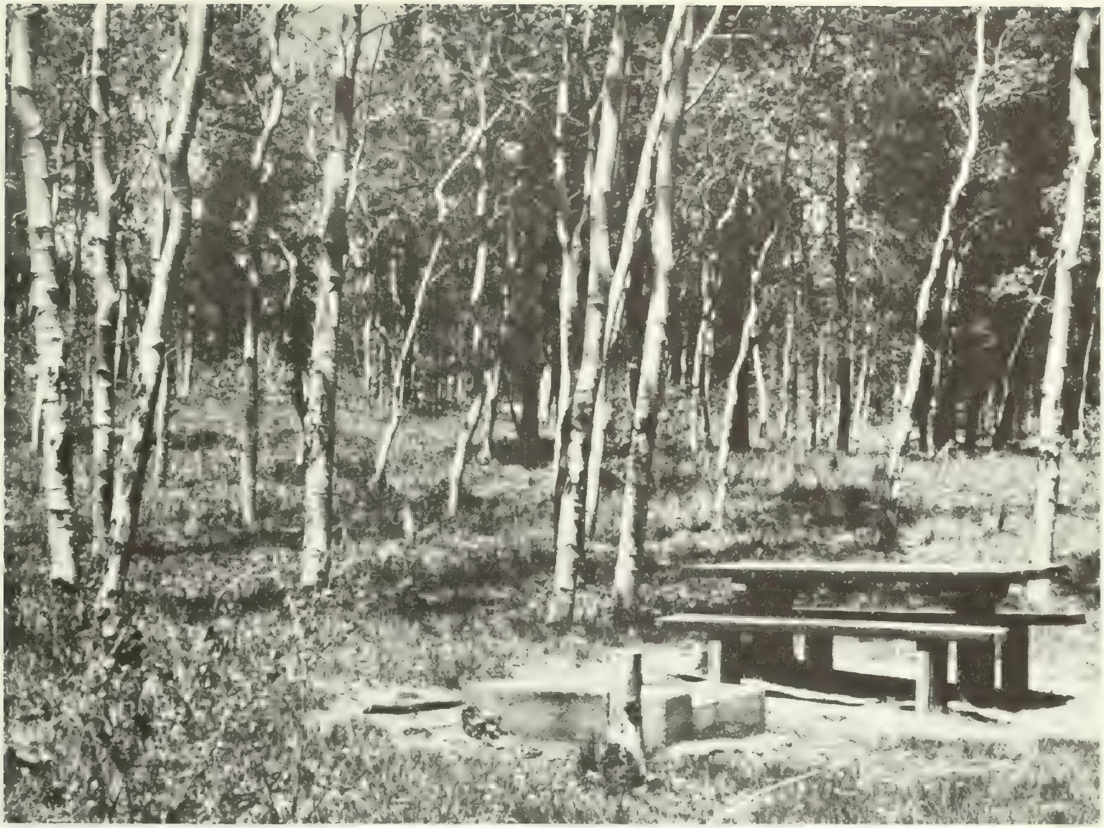
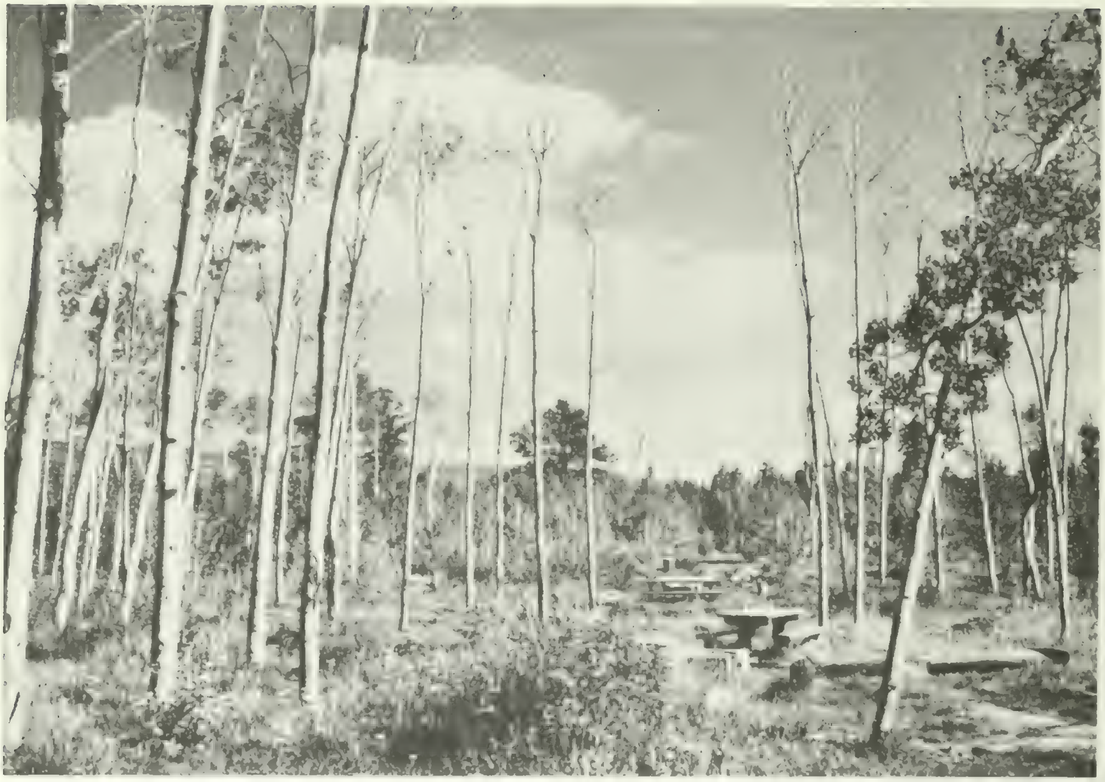


Figure 16.—Kenosha campground, Unit 2 interior plot, with 17 live trees: 14 are wounded, 13 cankered, and 9 over half girdled. Present tree loss is 6 cut and 2 down. Perimeter plot has 32 live trees, 7 cut, 1 down, and 1 dead standing. Average camp unit tree loss in this campground is 23 percent in 8 years.

Figure 17.—Maroon Lake campground. Unit 15 interior plot, with 7 live trees; 10 had been cut. The perimeter plot (68-ft 4-inch radius) has 6 live trees, with 26 cut. Trees on both plots ranged up to 19 inches in diameter at breast height. Average camp unit tree loss in this campground is 68 percent in 12 years.



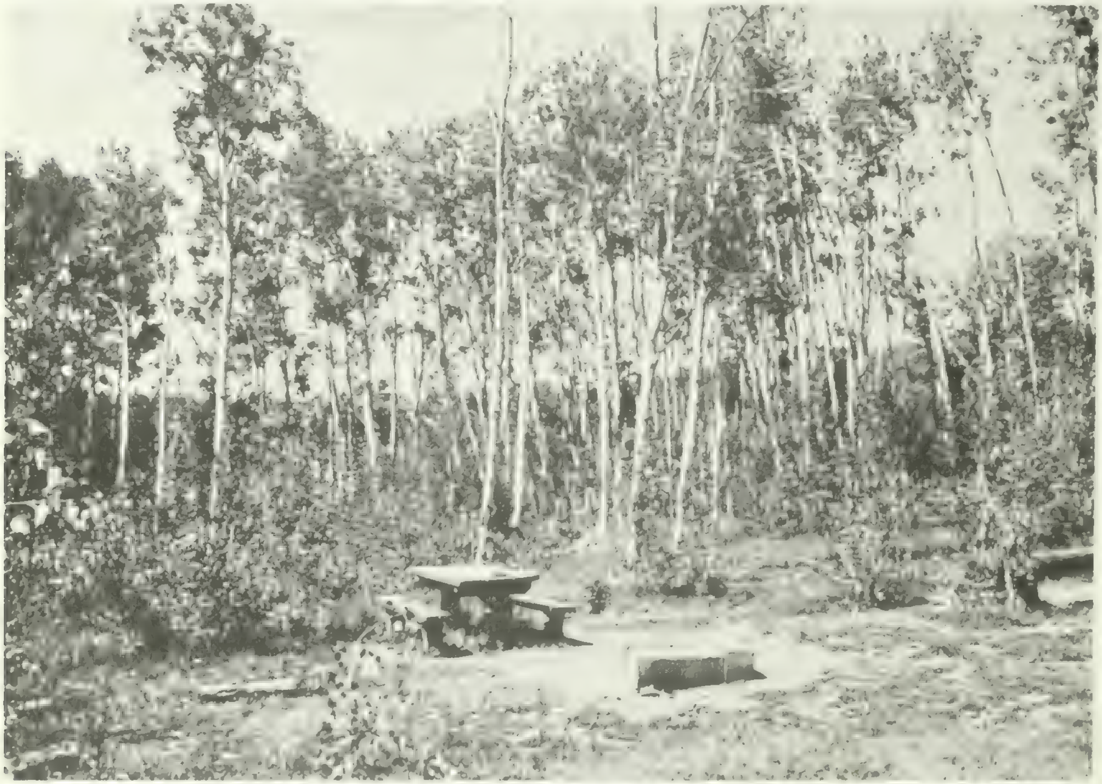


Figure 18.—Transfer campground. **Top:** View through central portion of campground in August in its final stages of deterioration, with complete lack of tree screening between campsites. Average campsite tree loss in this campground is 90 percent in 14 years. **Bottom:** Unit 4 interior plot with 2 live trees over half girdled by cankers, 11 cut, and 5 dead standing. Perimeter plot (80-ft 4-inch radius) has 16 live trees, 1 cankered, 73 cut, and 22 dead standing.

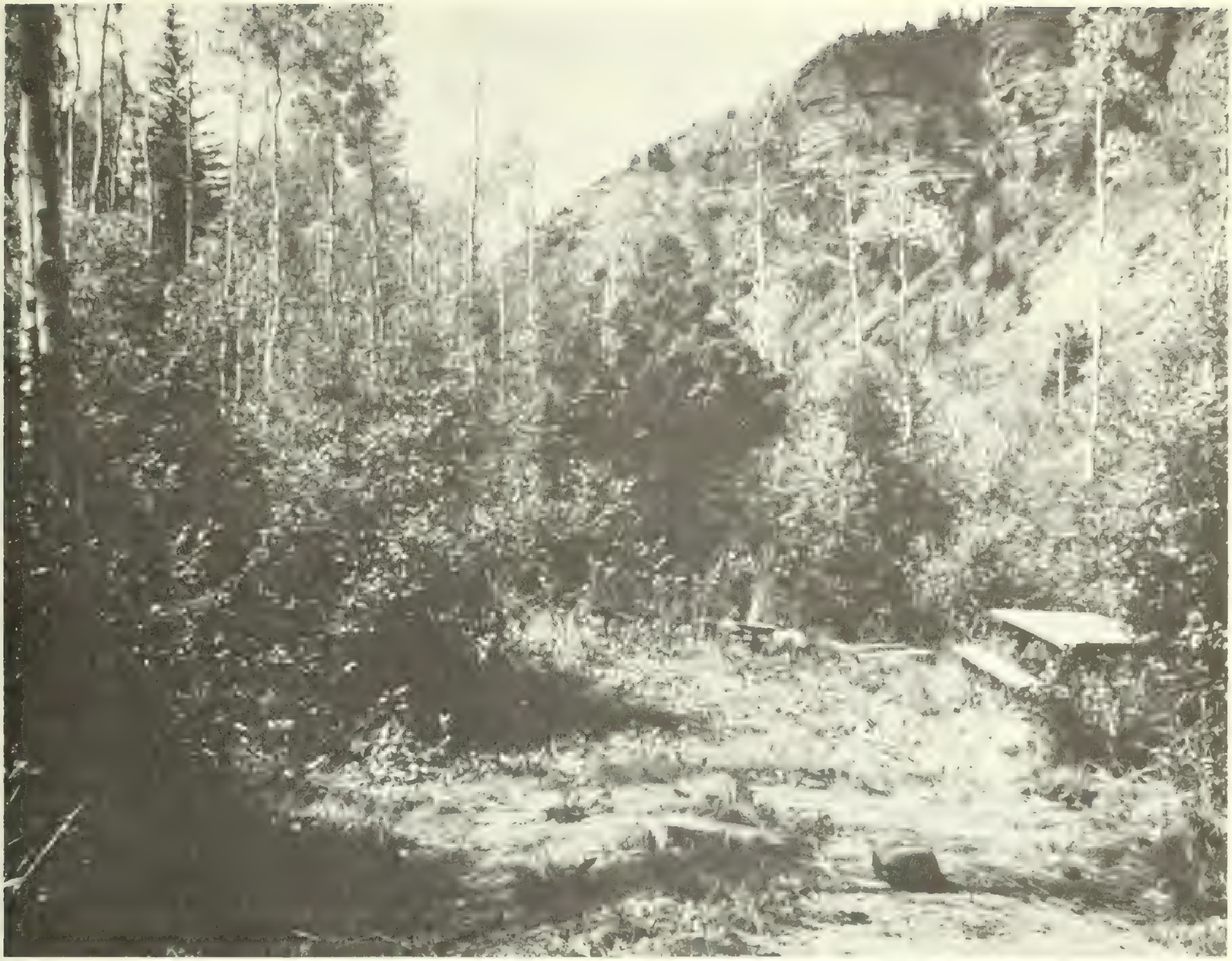


Figure 19.—Redstone campground. Unit 1 with 2 live trees: 1 wounded, 1 cankered and over half girdled. Average basal diameter of 22 cut trees in the interior plot was 5.3 inches. There were 23 live, 28 cut, and 5 cankered, dead standing trees on the perimeter plot (62-ft 4-inch radius). Average campsite tree loss in this campground is 94 percent in 21 years. Understory vegetation is now oak, aspen, and juniper.

Management Implications

The future of these aspen campgrounds is bleak. Many will have to be closed because of esthetic loss or lack of funds for proper maintenance. The eventual closure of some no doubt will go unnoticed, but closure of others, such as Maroon Lake, will be met by stern public criticism. The management of most, because of their recreation value, must be altered in some manner if the aspen resource is to be maintained. Some of the implications for management which can be concluded from this study are:

- Because campsite degradation as a result of tree loss is caused directly by recreationists, campgrounds should be constructed in a more durable forest-type than aspen if maintenance of a tree cover is important.

- Because of the frequency of mechanical injury to aspen trunks in campgrounds by recreationists, and because this damage is the main precursor to early tree mortality, interpretive signs need to be displayed in aspen campgrounds showing users why they should not injure tree trunks. Coupled with this, a forceful campaign to apprehend and prosecute violators should be instigated.

- Because mortality of the trees already injured will continue at an accelerated pace (there is presently no known way of arresting the progress of the canker diseases), dead tree removal will also have to be accelerated to maintain camper safety.

- Because of the anticipated fate of these aspen campgrounds, remedial possibilities include: (a) acceptance of unnatural or deteriorated conditions; (b) closure; (c) relocation as deterioration advances; (d) transplanting large conifers from offsite; and (e) site conversion on a long-range basis to other species less susceptible to visitor-caused injury. The foregoing biotic alternatives still need considerable research, however.

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Appendix

Table 3.--The proportion of living trees and associated damage in aspen campground plots in relation to campground age[1]

Campground	Age (years)	Living			Living trees that were:										
					Injured[2]		With cankers			More than one-half girdled			With wood borers		
		Inter- ior	Perim- eter	Inter- unit	Inter- ior	Inter- unit	Inter- ior	Perim- eter	Inter- unit	Inter- ior	Perim- eter	Inter- unit	Inter- ior	Perim- eter	Inter- unit
		Percent													
Freeman	4	90	93	85	97	22	53	8	4	27	2	0	18	0	0
Matterhorn	7	88	93	96	72	4	33	1	1	8	0	1	0	0	0
Snowblind	8	94	82	87	94	4	71	0	0	29	0	0	24	0	0
North Fork	8	80	83	79	64	4	64	40	67	26	5	33	11	6	7
Kenosha	8	77	79	67	88	44	57	8	14	27	5	5	39	0	0
Divide Fork	8	70	77	94	100	27	38	0	19	19	0	0	38	0	0
Sunshine	8	56	81	78	100	34	40	5	20	20	2	10	10	0	3
Weller	9	74	74	92	84	23	51	1	3	49	1	0	0	0	0
Difficult	9	64	71	75	75	3	39	0	11	12	0	5	23	0	5
Michigan Creek	9	37	54	72	93	45	100	40	18	79	26	14	7	0	2
Canjilon Lakes	11	87	91	93	93	4	33	1	2	10	1	0	14	0	0
Maroon Lake	12	32	60	49	58	6	39	5	18	19	3	5	3	1	9
Cimarrona	14	38	57	43	100	33	80	3	33	60	0	1	20	3	33
Transfer	14	10	13	11	100	75	100	17	50	0	17	25	50	13	25
Agate	16	66	68	70	63	7	44	1	11	27	1	3	27	0	2
Transfer Park	19	62	81	64	94	97	64	1	47	24	1	13	48	0	45
Redstone	21	6	34	49	50	13	50	3	8	50	3	4	50	0	[illegible]
Average	11	66	73	70	83	19	47	5	14	22	2	6	18	<1	5

[1] Basis: 967 stems in 53 interior plots, 4,875 stems in 52 perimeter plots, and 949 stems in the 45 inter-unit plots.
[2] No data recorded on perimeter plots.

Table 4.--The proportion of tree loss and probable cause in aspen campground plots in relation to campground age[1]

Campground	Age (years)	Tree loss			Dead trees that were:								
					Cut or windthrown			Standing dead			With canker[2]		
		Inter- ior	Perim- eter	Inter- unit	Inter- ior	Perim- eter	Inter- unit	Inter- ior	Perim- eter	Inter- unit	Inter- ior	Perim- eter	Inter- unit
		Percent											
Freeman	4	10	7	5	75	25	63	25	75	37	100	100	100
Matterhorn	7	12	7	6	100	78	50	0	22	50	0	75	100
Snowblind	8	6	18	13	100	80	75	0	20	25	0	100	100
North Fork	8	20	17	21	27	36	0	73	64	100	100	100	100
Kenosha	8	23	21	33	60	65	43	40	35	57	100	100	83
Divide Fork	8	30	23	6	86	100	0	14	0	100	100	0	100
Sunshine	8	44	19	22	87	96	100	13	4	0	100	100	0
Weller	9	26	26	8	94	100	33	6	0	66	100	0	100
Difficult	9	36	29	25	97	75	54	3	25	46	100	100	100
Michigan Creek	9	63	46	28	59	50	42	42	41	50	100	100	100
Canjilon Lakes	11	13	11	7	56	90	66	44	10	33	81	100	100
Maroon Lake	12	68	40	50	96	80	67	4	20	33	100	74	87
Cimarrona	14	62	43	57	94	94	100	6	6	0	100	100	0
Transfer	14	90	87	89	72	84	94	28	16	6	100	100	100
Agate	16	34	32	20	80	70	38	20	30	62	100	100	100
Transfer Park	19	38	19	36	90	85	80	10	15	20	100	100	50
Redstone	21	94	66	51	97	85	84	3	14	16	100	100	100
Average	11	34	27	30	28	21	19	6	6	11	98	94	93

[1] Basis: Total loss of 331 trees in 53 interior plots, 1,303 in 52 perimeter plots, and 283 in the 45 inter-unit plots.
[2] Tree death was attributed to a canker disease if a standing dead tree was girdled by a canker.

Common and Scientific Names of Diseases, Insects, Plants, and Vertebrates Mentioned

Diseases	
Artist's conk	*Ganoderma applanatum* (Pers. ex Wallr.) Pat.
Cenangium canker	*Cenangium singulare* (Rehm.) Davidson & Cash
Ceratocystis canker	*Ceratocystis fimbriata* Ell. & Halst.
Cryptosphaeria canker	*Cryptosphaeria populina* (Pers.) Sacc.
Cytospora canker	*Cytospora chrysosperma* Pers. ex Fr.
False tinder fungus	*Phellinus tremulae* (Bond.) Bond. et Boris
Honey mushroom	*Armillariella mellea* (Vahl. ex Fr.) Karst.
Hypoxylon canker	*Hypoxylon mammatum* (Wahl.) Mill.
Scaly Pholiota	*Pholiota squarrosa* (Fr.) Kumm.
Insects	
Bronze birch borer	*Agrilus anxius* (Gory)
Poplar borer	*Saperda calcarata* Say
Poplar butt borer	*Xylotrechus obliteratus* (LeC.)
Plants	
Aspen	*Populus tremuloides* Michx.
Juniper	*Juniperus* spp.
Oak	*Quercus gambellii* Nut.
Vertebrates	
Elk	*Cervus canadensis nelsoni* Bailey
Moose	*Alces alces shirasi* Nelson

Agriculture—CSU, Fort Collins

Hinds, T. E.
1976. Aspen mortality in Rocky Mountain campgrounds. USDA For. Serv. Res. Pap. RM-164, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Aspens die from canker disease infections as a result of mechanical injuries to the live bark inflicted by thoughtless campers. Dead trees usually are cut to reduce camper hazard. Aspen loss is related to campground age. A desirable aspen-type camp unit can be degraded to a treeless site of grass, forbs, and shrubs within 10 to 20 years. The management of aspen campgrounds must be altered if the resource is to be maintained.

Keywords: Recreation use impact, campground degradation, aspen mortality, insects, diseases, *Populus tremuloides.*

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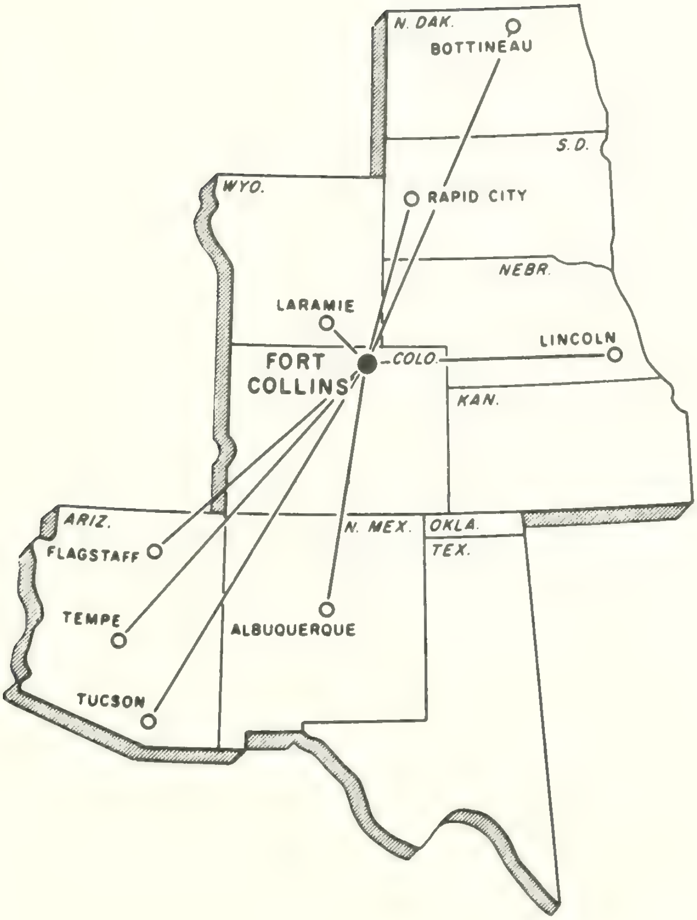
N. DAK.
BOTTINEAU
S.D.
WYO.
RAPID CITY
NEBR.
LARAMIE
LINCOLN
FORT COLLINS
COLO.
KAN.
ARIZ.
N. MEX.
OKLA.
TEX.
FLAGSTAFF
TEMPE
ALBUQUERQUE
TUCSON

April 1976

Crown Structure and Distribution of Biomass in a Lodgepole Pine Stand

Howard L. Gary

SEP 2 1976

USDA Forest Service
Research Paper RM-165
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Gary, Howard L.
1976. Crown structure and distribution of biomass in a lodgepole pine stand. USDA For. Serv. Res. Pap. RM-165, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Gross dimensions and quantities of needles and branches are presented for 298 trees. Weight, diameter, length, and height relations were usually highly correlated. Needles were normally distributed along the length of branches as well as vertically through the canopy. Needle and branchwood weights for entire crowns were best estimated by the logarithmic transformation of diameters at breast height.

Keywords: *Pinus contorta,* biomass, canopy, foliage, overstory productivity, transpiration.

USDA Forest Service
Research Paper RM-165

April 1976

Crown Structure and Distribution of Biomass in a Lodgepole Pine Stand

Howard L. Gary, Hydrologist
Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained at Fort Collins in cooperation with Colorado State University.

Contents

Page

Introduction 1

Previous Work 1

  Crown Characteristics 1

  Needle Size and Persistence 1

  Needle and Branchwood Surface Area 1

  Crown Weight Prediction 2

Study Area 2

Methods 2

Results and Discussion 4

  Crown Component Relations 4

    Crown Length, Height, and Bole Diameter 5

    Branching Characteristics 5

    Radial Spread and Vertical Rise of Branches 6

    Branch Diameter-to-Length and Age 7

    Needle Persistence, Distribution, and Size 9

    Surface Area of Needles, Branches, and Bole 10

  Weight Relations of Needles and Branches 10

    Green vs. Dry Weight 10

    Needle vs. Branch Weight 12

    Diameter vs. Length of Branches 12

  Distribution of Needles and Branch Weight 12

    Weight Distribution Along Branches 13

    Vertical Weight Distribution in the Crown 14

  Crown Weight Estimates 15

Summary and Conclusions 18

Literature Cited 19

Crown Structure and Distribution of Biomass in a Lodgepole Pine Stand

Howard L. Gary

INTRODUCTION

The quantity and arrangement of leaves and branches in tree crowns have long been of interest to foresters, ecologists, and plant physiologists. Much recent interest in tree crowns has been related to their efficiency in trapping and dispersing man-caused aerosols (Brady 1967). The sound-attenuating properties of tree and shrub crowns for noise control have been evaluated by Cook and van Haverbeke (1971). The potential of tree crowns as raw material for oils and pharmaceuticals is also under study (Keays 1971). Detailed crown structure information should be gathered prior to studies of forest productivity and nutrient cycling, and fuel description for fire control operations (Ovington and Madgwick 1959, Deeming and others 1974).

A characteristic need in the above interdisciplinary studies of tree crowns is for more detailed knowledge about the dimensions and quantities of foliage and branches, and interrelationships between them. The horizontal and vertical distribution of foliage and branches must also be better understood if we are to realize the full potential for organic production, energy exchange, nutrient cycling, effects of fertilization, water balance in response to climate, and similar factors. This study reports size and weight interrelations of lodgepole pine (*Pinus contorta*) needles, branches, and boles.

PREVIOUS WORK

Crown Characteristics

Branching in lodgepole pine crowns, as in most conifers, is excurrent: an undivided main stem or bole supports whorls of branches radiating outward. Stiell (1962) reported for red pine (*P. resinosa*), "The crown is by no means uniformly dense: the stem and a zone around it occupy a needle-free core up the center; there are gaps between the foliage of successive branches, both horizontally and vertically; and the weight of the foliage itself varies erratically from one branch whorl to another." Similar characteristics are apparent in lodgepole pine. Differences in site quality, spacing, and genetic factors apparently all contribute to the wide variation of crown characteristics of individual trees, and in stand development (Curtis and Reukema 1970). The growth of branches, as well as that of needles, reflects such factors as: position within the whorl, subsequent shading by neighboring branches and whorls higher in the crown, available soil nutrients, and climatic conditions (Madgwick 1967).

Needle Size and Persistence

Needle size and persistence also vary significantly with position in the crown, from tree to tree, year of formation, species, and soil fertility (Heiberg and others 1964, Hall 1966, Brix and Ebell 1969, and Smith 1972). For red pine, Madgwick (1967) reported that average weight of individual needles on branches at the base of the crown was 36 to 50 percent of the average weight of individual needles on the topmost whorl. He believed that "future effects of shading on total weights of needles may be postulated as a result of the death of growing points, the increasing ratio of respiring branch tissue to photosynthesizing needle tissue . . ." Most dendrology textbooks indicate that lodgepole pine needles persist 4 to 6 years.

Needle and Branchwood Surface Area

Needle surface area has long been used as a basic parameter for expressing physiological activities such as photosynthesis and transpiration. Surface area estimates obtained indirectly from photoelectric methods (Kramer 1937), projected surface areas (Barker 1968), volume measurements (Ronco 1969, Lopushinsky 1970), and weight measurements (Cable 1958, Mellor and Tregunna 1972) are usually linearly and highly correlated with the direct surface area measurement method used by Kozlowski and Schumacher (1943).

The surface area of branches is also an important dimension of forest stands, with implications for respiration rate, energy exchange, water balance, and nutrient cycling. Surface area of branches has been satisfactorily estimated when "conceived in terms of a basal or first-generation segment which forks into two second-generation segments of smaller diameters, each of which forks into two third-generation segments of still smaller diameters, and so forth" and then computed as conic surfaces (Whittaker and Woodwell 1967).

Crown Weight Prediction

The moisture contents of bark, sapwood, and heartwood of larger branches vary only slightly from the bottom to the top of the crown and through the year (Smith 1971, Markstrom and Hann 1972). In contrast, the water content in small branches and needles varies greatly, both diurnally and seasonally, in response to age and changing environmental factors (Gary 1971). Equations for estimating total crown weight can, however, be developed from green weights of branches and needles by establishing (and periodically updating) a relationship to more easily measured variables such as diameter at the base of live crown, and ratio of live crown length to tree height (Kittredge 1944, Storey and others 1955).

Extrapolation of individual crown weights to a land area basis generally involves (1) counting trees by species and size and/or some form of size stratification, and (2) relating the data from (1) by regression analysis to the more easily measured variables (especially d.b.h.) (Arts and Marks 1971).

Foliage and branchwood weights of individual crowns have also been satisfactorily estimated from branch diameters. First, regression constants are established relating branch diameter to weight; then diameters of all branches are measured, and predicted weights for all branches on the tree are summed (Loomis and others 1966). Difficulty in determining branch diameters in tall trees has usually limited the wide use of this method.

Weight distribution through vertical or horizontal sections of tree crowns is seldom estimated. In the few reported studies for conifers, foliage weight was apparently normally distributed both vertically through the crown and along the length of branches (Tadaki 1966, Stephens 1969).

Branch size stratification and limited sampling of various sized branches within individual crowns provides another good method for obtaining weight-size relations (Baker 1948). Stratification procedures also offer great possibilities for obtaining considerable information about branches themselves—such as frequency distribution of diameters, lengths, annual growth, needle concentrations, and other characteristics.

For lodgepole pine stands in Canada similar to those in the present study, Johnstone (1971) reported needles made up about 5 percent and branches about 6 percent of the total dry weight above 0.3-m- (1-ft) high stumps of an unthinned stand averaging about 16 cm (6.4 inches) d.b.h., 16.8 m (55 ft) tall, and about 2,470 living stems per ha. Average tree weight above the 0.3-m stump was about 78.4 kg (210 lb). In a "dog hair" stand, he reported needles averaged about 8 percent and branches about 16 percent of the aboveground dry weight for trees averaging about 5.6 cm (2.2 inches) d.b.h., 5.8 m (19 ft) tall, and about 12,350 stems per ha. Average tree weight above the 0.3-m stump was 7.3 kg (16 lb). Both stands were 100 years old.

STUDY AREA

The primary study area was in a large expanse of lodgepole pine forest about 3.2 km southeast of Foxpark, in southern Wyoming. The stand was on a gently rolling plateau about 2,743 m above m.s.l. Slopes in the area averaged less than 5 percent. The forest was thinned during the early 1940's to a spacing of about 2.3 m (7.5 ft) and about 2,000 stems per ha. A stagnant "dog hair" portion of the study stand had a stocking of about 25,000 stems per ha. All trees were about 80 years old. In the thinned stand, the height range of 285 study trees was 7.3 to 14.9 m and average height about 10.8 m (35.5 ft). The d.b.h. ranged from 6.6 to 19.8 cm and averaged 13.2 cm (5.2 inches) (fig. 1). Five "dog hair" trees were also sampled. Their average height was 7.5 m (24.5 ft), and average d.b.h. was 5.6 cm (2.2 inches).

Eight additional trees were sampled in a thinned stand, on a steep northeast-facing slope near Pingree Park, Colorado. Elevation, age, and stand structure were about the same as observed above. The area was about 80 km south of the main study area. Average height of the eight study trees was 9.4 m (31 ft) and d.b.h. was 14.7 cm (5.8 inches).

METHODS

Field measurements were made during August 1970, 1971, and 1972. All sample trees were in areas cleared to establish small openings (<0.2 ha) for other studies.

The individual trees used for various parts of the study were subjectively selected as being representative of the existing stand. For convenience of the reader and because of the number of relations studied, some statements regarding methods are also presented in the Results section. All measurements are reported as metric units. The following gross measurements were recorded for all study trees: d.b.h., total height, height to first dead whorl, and length of all-live crowns. For greater handling and sampling convenience, the all-live crowns were stratified into three height sections, and data were recorded by lower, middle, and upper crown thirds. Whorl heights were recorded for about one-third of the 298 study trees. Because measurements of surface area relations and horizontal weight distribution of needles and branchwood were extremely time consuming, they were limited to one and two trees, respectively.

In 1970, eight trees were intensively dissected and sampled. Measurements on five of the trees include whorl heights, diameter of all branches 5 cm from the bole, length of branch axes (central line of branchwood), ovendry (100°C) weight of branches and needles, vertical rise and horizontal spread of branches, and vertical angle of branches measured 15 cm from the trunk. Measurements on one tree also included total length of individual branches (axes plus length of all side branches); computed surface areas of needles, branches, and bole; and age, persistence, weight, and number of needles. The horizontal distribution of needles and branchwood weight by whorls and branch azimuth were also determined for two of the trees. Horizontal weight distribution was determined after laying all branches within each whorl side by side so as to fit on a 60-cm-wide cutting board. The branches were held in place by 10-cm-wide hinged guides, cut into 10-cm segments, ovendried, and weights obtained for needles and branches (fig. 2).

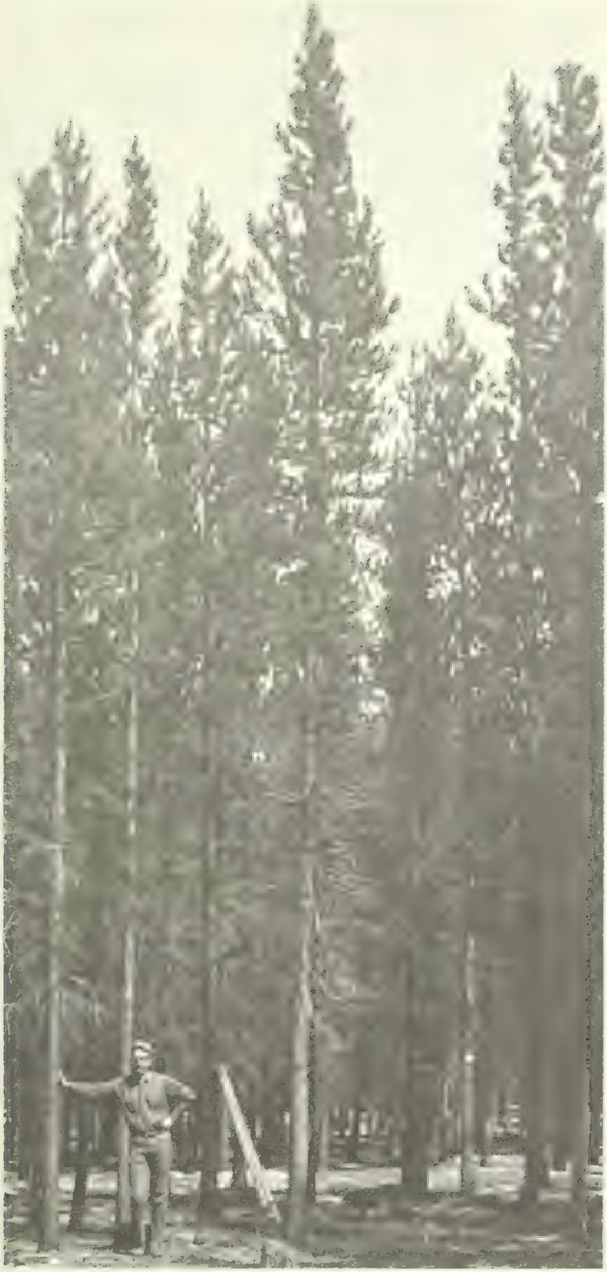

Figure 1.—Relative size, crown form, and spacing of the study trees near Foxpark, Wyoming.

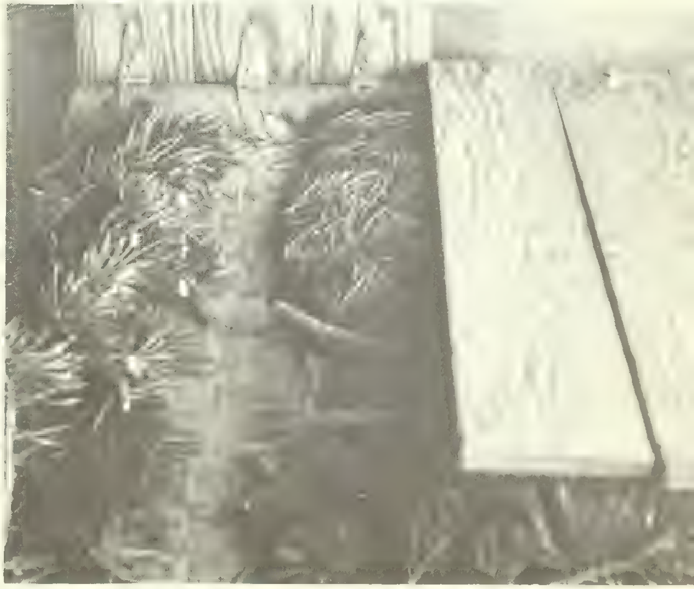

Figure 2.—Board with hinged 10-cm-wide leaves to guide cutting of branches for horizontal weight distribution of needles and branchwood.

For trees less intensively sampled in 1970, branch lengths and diameters, height of branch whorls, and their green and ovendried weights were determined for one group of 10 trees. Ovendry weights of whorls were also obtained for five trees from an adjacent "dog hair" stand. Ratios of green-to-dry weight were also determined for one group of 27 trees. Total green weight of all branches by crown thirds was also determined for another group of 49 trees (fig. 3). Their dry weights were estimated.

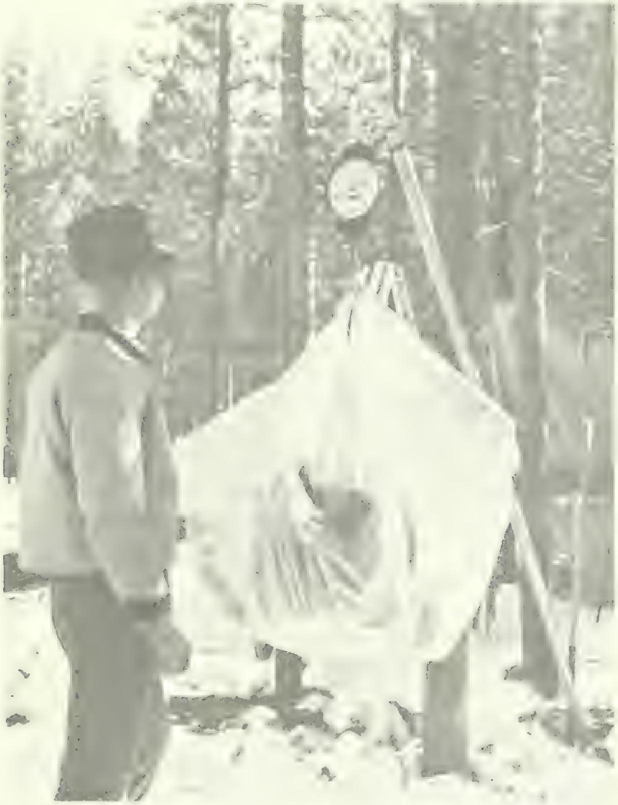

Figure 3.—Method of obtaining green weight of all branches in a crown section.

Eight trees were sampled in 1971 at Pingree Park to obtain ratios of green-to-dry weight and branch diameter-to-length relations in order to make relative comparisons with similar data from trees at Foxpark.

In 1972, the gross measurements for 191 trees removed to enlarge a clearing at Foxpark included d.b.h., height to first dead whorls, height to all-live whorls, and total height. Green and dry weights of selected branches were obtained for 17 trees, and were later used to estimate dry weights of the crown sections and the whole crown.

Surface areas of needles and branches were also estimated for one intensively sampled tree. The fascicles of lodgepole pine usually consist of two needles which form an approximate cylinder when pressed together. Each needle has one flat inner face and one curved outer face. Surface area was thus computed by adapting the method of Kozlowski and Schumacher (1943). The surface area of branchwood was computed from branch segments using the method of Whittaker and Woodwell (1967). All branch segments were assumed to be a frustum of a cone. The basic formula used for determining surface area of branch segments was:

$$S = \pi(r_1 + r_2)\sqrt{\ell^2+(r_1-r_2)^2}$$

where S is surface area, r is radius, and ℓ is length. The surface areas of the branch segments were summed to obtain a surface area estimate of individual branches. Bole surface area was determined for increments corresponding to the whorl height using the formula above.

RESULTS AND DISCUSSION

Crown Component Relations

Differences in sites, spacing, environment, and other factors all contribute to wide variation of crown characteristics. Figure 4 illustrates the wide variability of the crown length parameter and the lower and upper limits of the canopy for one intensively sampled group of 10 trees.

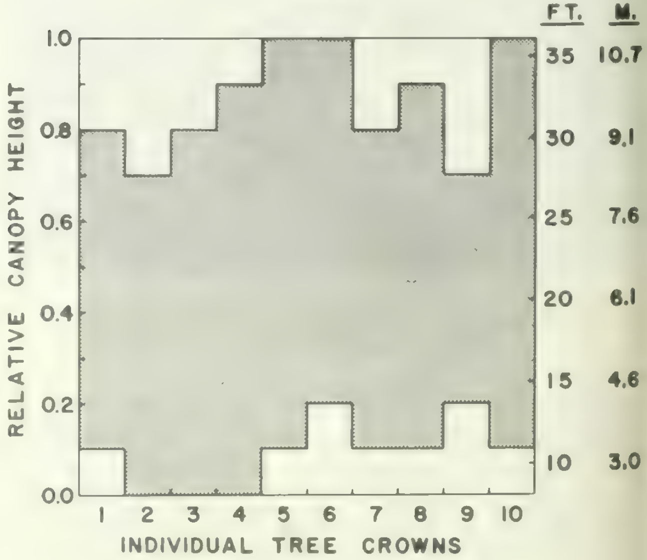

Figure 4.—Representation of a 10-tree canopy and crown length variability.

Crown Length, Height, and Bole Diameter

Average height and standard deviation to the first dead whorls for 285 trees in the thinned stand at Foxpark was 1.7 ± 0.4 m. For the five trees in the adjacent "dog hair" stand, average height to the first dead whorls was 1.4 m. Many of the dead branches were more than 40 years old in both stands. Dimensions and weights of dead branches were not determined.

Height to the live crown and its standard deviation averaged 4.6 ± 0.9 m for the thinned stand, and height averaged 4.5 m for the "dog hair" trees. Crown length and tree height were significantly correlated with d.b.h., but were probably not the consequence of common factors such as quality of light. The sample correlations between live crown length and d.b.h. and tree height and d.b.h. accounted for 36 to 56 percent of the total variation, respectively. In a two-way average relationship between crown length and tree height, the regression equation accounted for 48 percent of the variation. Average crown length and average length-to-height ratio for 285 trees in the thinned stand, five "dog hair" trees, and eight trees at Pingree Park were as follows:

	Crown length	Ratio crown length to tree height
	m	
Foxpark thinned trees	6.2	0.576
Foxpark "dog hair" trees	2.7	.353
Pingree Park trees	6.2	.661

Branching Characteristics

Two types of branches were consistently observed in the annual whorls of all study trees. The main (nodal) or larger branches in the whorls developed from the lateral buds at the apex of each leader. Internodal branches were usually much smaller and developed later in the growing season from buds distributed along the leader (fig. 5). Similar branch development is common to many conifers (Stiell 1969). No attempt was made to measure the two types of whorl branches separately. The number of live whorls for the Foxpark trees averaged 27. Number of branches per annual whorl ranged from one to eight and averaged 4.1. The ratio of foliage to branchwood weight increased from the lower crown section (one-third of crown) upward. An example based on averages for 10 trees was:

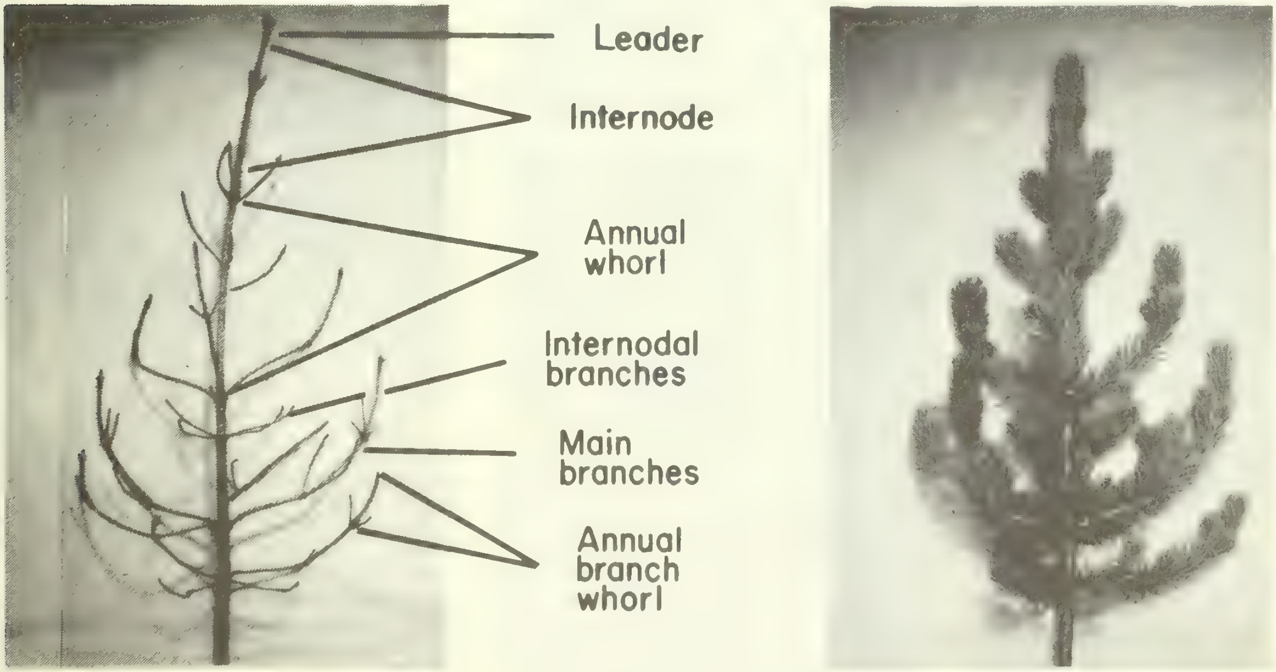

Figure 5.—Position of branch components on a lodgepole pine sapling.

Crown position	Weight ratio, needles to branchwood
Upper	1.6
Middle	1.5
Lower	1.0

The decreasing foliage per whorl or branch appeared highly dependent on light quantity and quality; the light environment apparently accounted for the low needle-to-branch ratio in the lower crowns (Stiell 1962). The more active growth and extension of branches higher in the crown or in the canopy eventually shades out the needles on the lowest whorls, and branches die.

Radial Spread and Vertical Rise of Branches

There was no significant difference among numbers of branches or radial distribution of branches between quadrants within crown sections or between trees. Stiell (1962) also reported no significant departure from radial symmetry of branches of red pines in a plantation.

Branch tips, regardless of age or position in the crown, generally pointed upward (fig. 6). Branches were relatively straight and longer in the lower half of most crowns, and their extension was mainly horizontal. In the upper crowns the branches were shorter, were pointed upward, and had less curvature near the branch tips. Apart from being dependent on

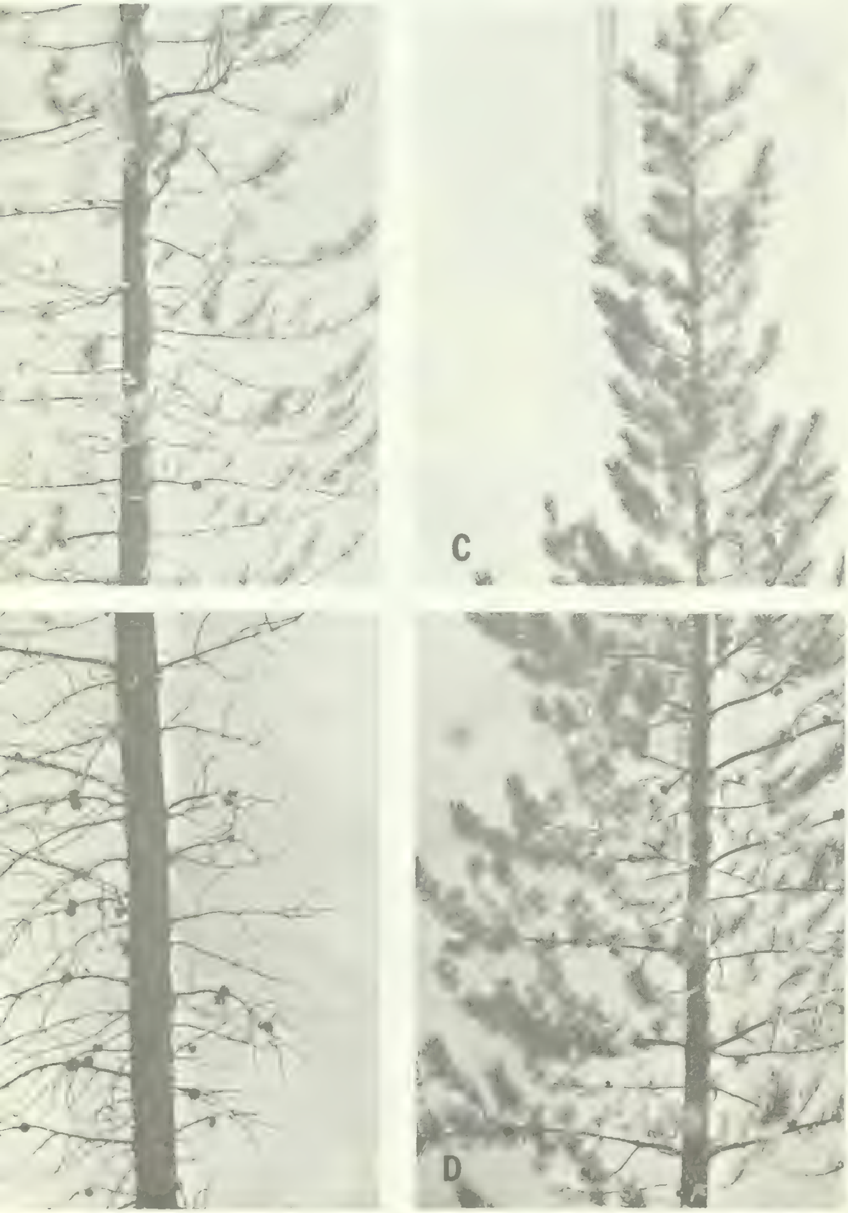

Figure 6.—Horizontal spread and vertical rise of branches on a 10-m lodgepole pine: **A**, lower crown; **B**, dead branches; **C**, upper crown sections; and **D**, middle crown. Length of crown sections about 2 m.

length, the relations between horizontal spread and vertical rise of branches were highly variable and poorly correlated. As was evident from the photographs in figure 6, the angles between the bole and the branches were steeper from the younger and shorter branches in the upper crown sections (fig. 7).

In the lower crown sections, lower branch angles were also apparent for the older and longer branches. The negative angles in figure 7 show that some branches were pointed downward. The angle or general position of older branches in the lower and middle crown sections were apparently succeedingly influenced by the annual weight and length increments of new growth and competition for space and light. Stiell (1962) observed similar patterns for red pine, where new lateral branches were nearly vertical. He noted that increasing needle numbers displaced branches outward, and that succeeding annual growth weighed them down. Over time, weight stress was removed by needle cast, and branches responded by curving upwards and eventually reflexing their tips.

Branch Diameter-to-Length and Age

Branch diameter and length were highly correlated at both Foxpark and Pingree Park. The correlation coefficient between lengths and diameters for 493 normally developed branches on five trees at Foxpark was 0.93, and 0.84 for 89 branches from eight trees at Pingree Park. The equation for the regression of branch length (axis) on branch diameter for the Foxpark trees was:

$$\hat{Y} = -11.30 + 68.76X$$

where $\hat{Y}$ was estimated branch length (axis) in cm and X was branch diameter in cm.

Measuring the total length of branches was time consuming because of the number of secondary, tertiary, and other divisions of the branchlets. To gain some knowledge of the spatial quality of branch length, however, the total length of all branchlets was determined for one tree at Foxpark. Figure 8 shows the regressions between branch diameters and

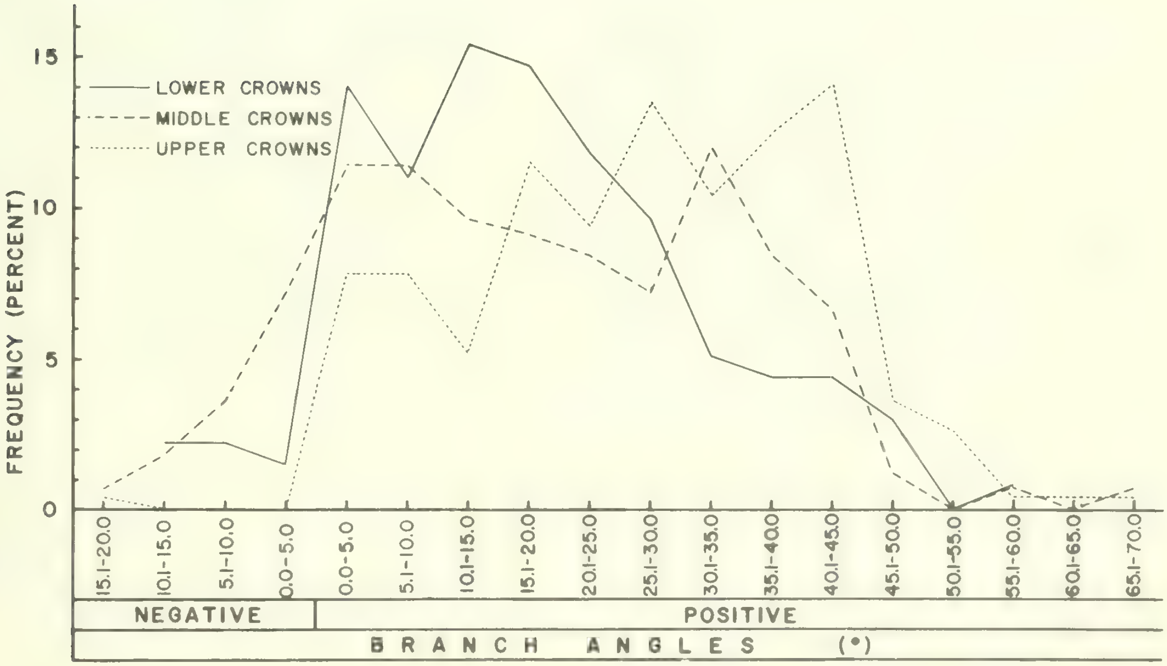

Figure 7.—Frequency distribution of branch angles (measured 15 cm from bole) for 493 branches on 5 trees.

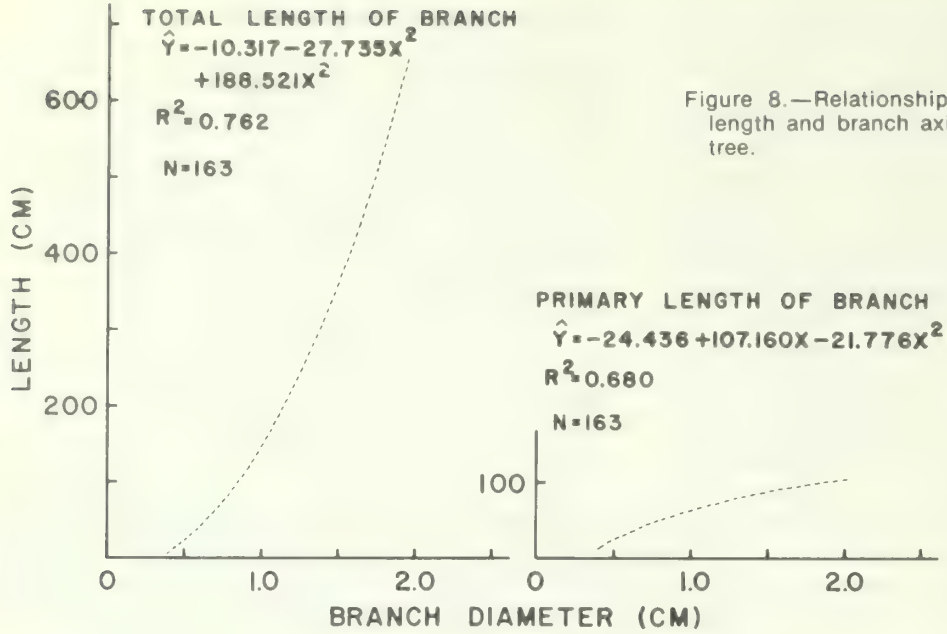

Figure 8.—Relationships between diameter and total length and branch axis length for 163 branches on 1 tree.

primary length (branch axis) of branches, and total length of the same branches. Of the 163 branches on the study tree, 50 were unbranched. The "straight" branches were mainly the smaller internodal and current-year branches; length was usually less than 40 cm. On the average, total length for individual branches was about three times greater than primary branch length, and ranged up to six times greater.

Branch environment apparently had more influence on growth than did age. Branch age (years since development), for all branches on 10 trees at Foxpark, was very poorly correlated with either average or longest branch length, or with branch diameter (r values<0.2). Other general relationships —such as that between primary length and total length of branches (sum of all side branchlets) for 163 branches on one tree—were highly correlated, however (fig. 9). Regression analysis accounted for about 77 percent of the variation, and provided a qualitative measure of total length of branches for all reaches of the crown.

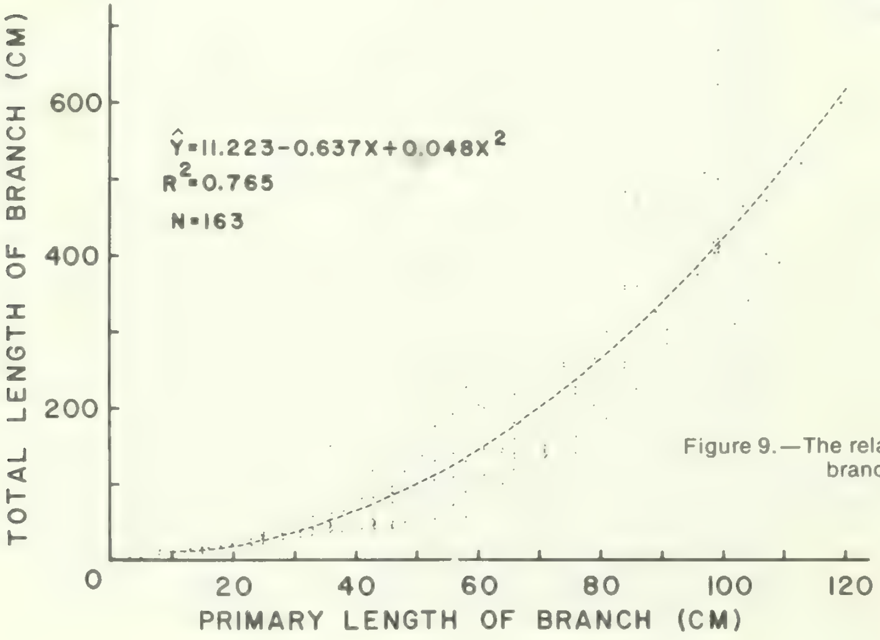

Figure 9.—The relationship of primary and total length of branches for 1 tree at Foxpark.

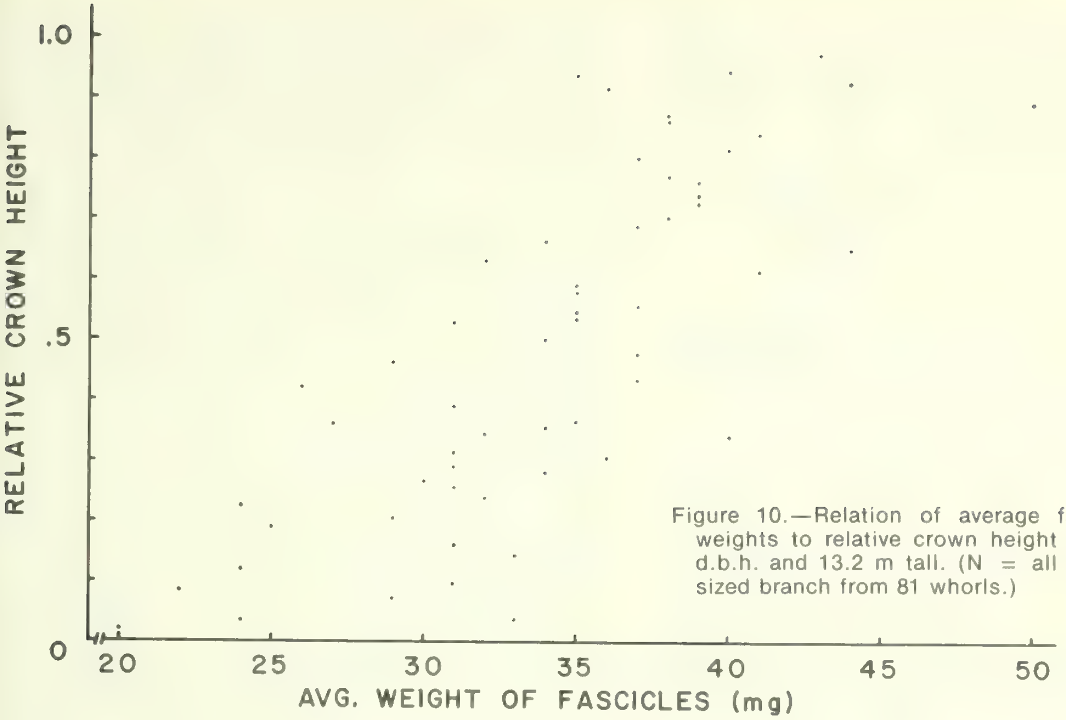

Figure 10.—Relation of average fascicle (2 needles) weights to relative crown height for one tree 13 cm d.b.h. and 13.2 m tall. (N = all needles on median-sized branch from 81 whorls.)

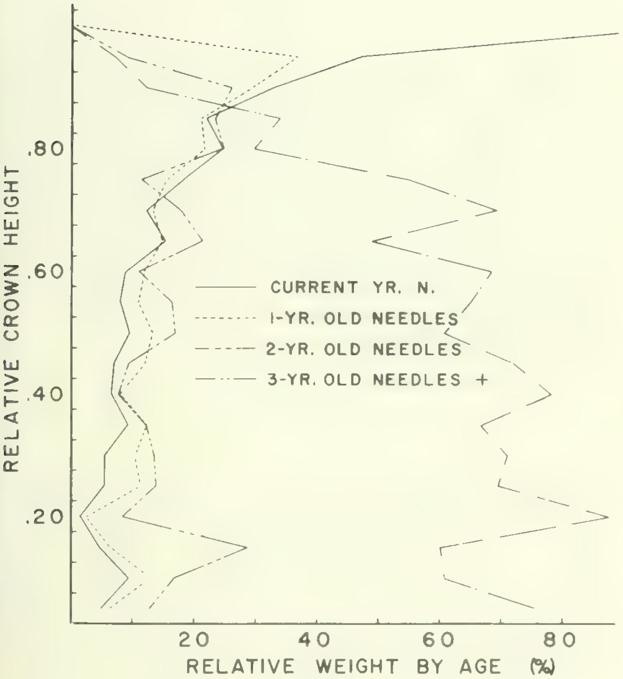

Figure 11.—Age distribution of needle fascicles scaled to percent of ovendry weight and relative crown height. Data for one tree (see fig. 10).

Needle Persistence, Distribution, and Size

Before average values can be applied to needle size and weight, we must learn more about their distribution and variability within the crowns and in the canopy. The reported trend (Madgwick 1967) of increasing weight of fascicles with height in the crown was carefully documented for one tree 13 cm d.b.h. and 13.2 m tall (fig. 10). Analysis of the relative distribution of needle ages for the median-sized branch from annual whorls on the same tree showed that the quantity of needles 3 yr of age and older was greatest in the lower quarter of the crown and least in the upper quarter (fig. 11). The weight percentages of current-year, 1- and 2-yr-old needles were highest in the upper quarter of the crown. The relative weight percentages of the younger needles were about the same through most of the middle and lower sections of the crown, with a tendency for lower weight percentage of current-year needles. The age distribution of fascicles for the whole tree, based on ovendried weights, was:

Needle age	Percent of total weight
Current year	10.7
1 year	12.6
2 years	14.3
3 years and older	62.4

Needle lengths and their standard deviations for a sample of 100 fascicles randomly collected from the composited foliage of 10 trees at Foxpark, and from eight trees at Pingree Park were:

Site	**Average needle length** (*mm*)
Foxpark	49.6 ± 7.7
Pingree Park	40.9 ± 8.7

The coefficient of variation for length was 16 percent at Foxpark and 21 percent at Pingree Park. Needle lengths were significantly different between the two areas.

Average fascicle weight computed from 100 samples, each consisting of 100 fascicles of all ages and from all sections of one tree at Foxpark, was 0.034 ± 0.009 gram. The coefficient of variation for weight was about 26 percent and indicates the large range of needle sizes. Smith (1972), working with Douglas-fir (*Pseudotsuga menziesii*), reported an average coefficient of variation of about 12 percent for needle length. He also believed the wide variation in weight and persistence within and between trees should be considered in documenting future studies.

Surface Area of Needles, Branches, and Bole

The total surface area for 25 branch and 25 bole fascicles was estimated from five diameter measurements taken at equidistant intervals along each fascicle from base to tip (Kozlowski and Schumacher 1943). The average total surface area was computed to be 304 mm^2 per branch fascicle and 441 mm^2 for fascicles on the upper bole.

The total surface area of needle fascicles was estimated for a sample of 170 branches on one 13-cm-diameter and 13.2-m-tall tree. Total surface area was determined as follows:

number of fascicles (computed from weight)
× average surface area per fascicle

Total surface area of branch fascicles were highly correlated with both branch diameter ($r = 0.95$) and branch weight ($r = 0.95$). The regression equation using branch diameters (<2.5 cm) to estimate total surface area of fascicles was:

$$\hat{Y} = -0.104X + 0.359X^2$$

where $\hat{Y}$ was estimated total area (m^2) of needle fascicles on the branch and X was diameter in cm. With further sampling on additional trees to establish regression constants, the use of other variables such as d.b.h. and crown length would probably be satisfactory for indirectly estimating needle surface area for entire trees.

Surface area of the branchwood was also computed for the 170 branches by the segment method of Whittaker and Woodwell (1967). Cumulative curves were plotted for surface area of needles, branches, and bole section of the crown for the sample tree (fig. 12).

An estimated 144,000 two-needle fascicles were contained within the crown. If all needles on the one tree were placed end to end, they would reach nearly 14.5 km (9 mi)! Assuming the tree was average for the stand, the needle or leaf area index defined as the ratio of total needle surface area of all trees to unit of ground area (m^2/m^2) was about 8. Moir and Francis (1972) reported a leaf area index of 4.3 for a low-productivity lodgepole pine stand in Colorado of about the same age and density as the stand at Foxpark. They also reported a leaf area index of 14 for a stand of moderately high productivity and twice the density but the same age as the Foxpark stand.

The 50 percent level of cumulative bole surface area, because of upward taper, was located in the lower third of the crown. For needles and branches, the 50 percent level of total surface area was reached near midcrown, and suggested a normal distribution of surface area within the crown region. Needle surfaces accounted for about 82 percent of the total calculated surface area.

Weight Relations of Needles and Branches

In destructive tree sampling, it is usually easier to obtain dry weights of leaves and branches than to measure their actual sizes or numbers. The component weight relations, once developed, offer a simple indirect method to obtain considerable information about various hard-to-measure branch parameters. Weight component relations of branches are readily adapted to simulation and other types of studies that seek to evaluate and maximize organic production in response to climate, fertilization, and similar relationships.

Green vs. Dry Weight

Moisture percentage of needles plus branchwood was plotted in relation to relative crown height for 234 whorls on 10 trees at Foxpark (fig. 13). The samples were taken during one day in August 1970. The higher average moisture content in the upper crown section was due to a higher proportion of needles and younger and succulent branchwood.

It was impractical to dry and weigh all branches on all trees for dry weight determination. However, good estimates of branch dry weights were obtained after sampling a few trees because of the generally excellent correlation between green and ovendry

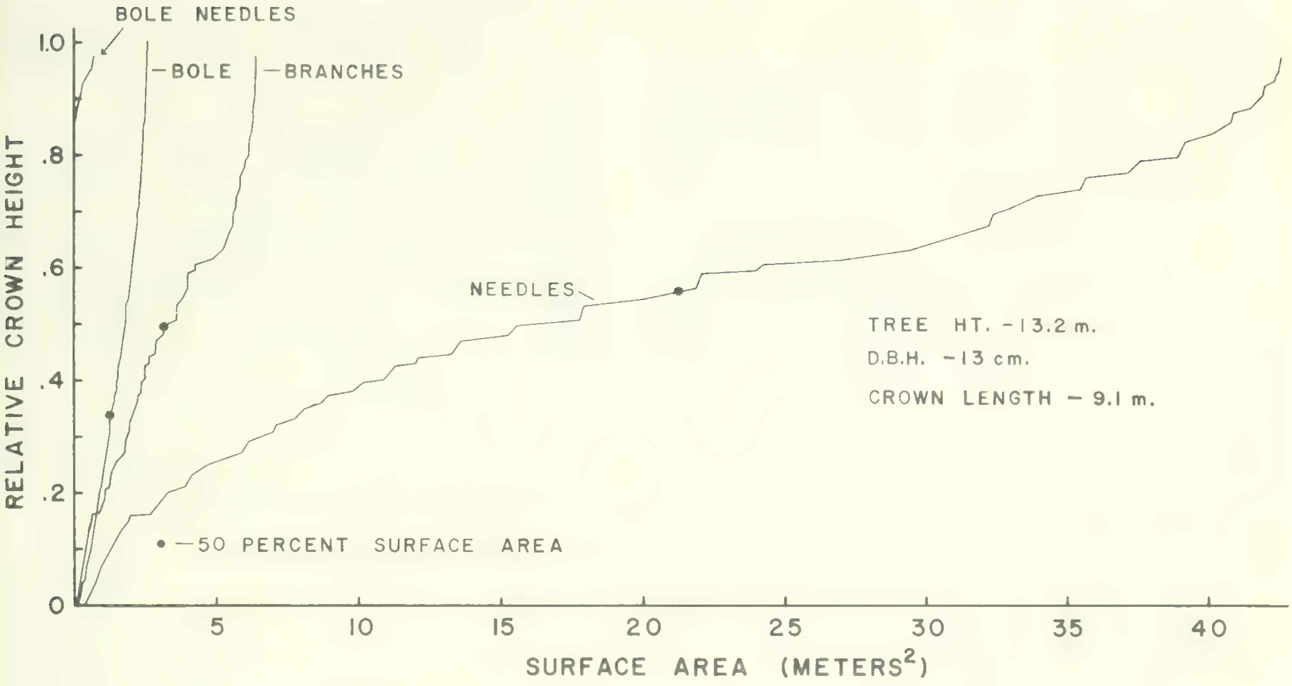

Figure 12.—Cumulative curves of estimated total surface area of needles, branches, and bole sections for one tree.

weight. Equations for estimating dry weight were developed from the green and ovendried weights of all branches in the 234 whorls mentioned above and from 89 branches taken from eight trees at Pingree Park in August 1971:

Foxpark $\hat{Y} = 2.18 + 0.49X$
Pingree Park $\hat{Y} = -0.24 + 0.52X$

where $\hat{Y}$ was estimated dry weight of needles plus branches, and X was green weight of needles plus branches. Weights were in grams. Both regressions accounted for more than 99 percent of the sample variation, and their slopes were not significantly different. The high correlations indicated the regressions were generally applicable for all branches from both the lower and upper crown sections, and varying moisture content had little apparent effect on dry weight estimation. The regression constants for dry weight estimation should be recomputed occasionally because of seasonal changes in moisture contents.

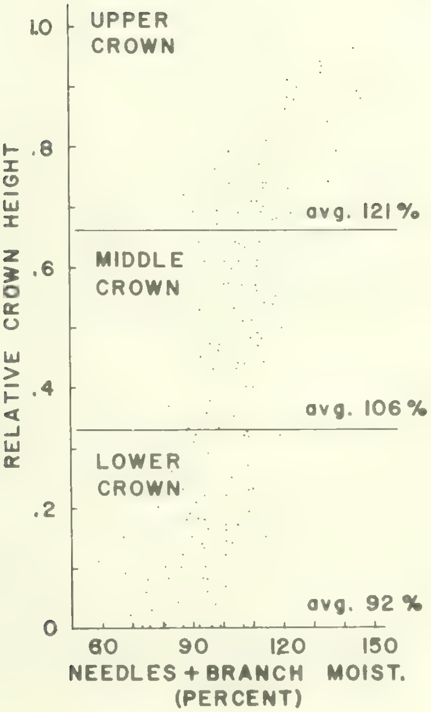

Figure 13.—Needle-plus-branch moisture in relation to relative crown height for 234 whorls on 10 trees at Foxpark. Percent moisture determined as: $\frac{\text{green weight - ovendry weight}}{\text{ovendry weight}} \times 100$.

Needle vs. Branch Weight

The time and labor required to separate needles from green branchwood is usually prohibitive. However, in the present study, reliable estimates of dry needle weights were obtained from regression analyses that utilized branch weights (needles plus branchwood). Regression equations were developed after ovendrying and weighing sample branches. Branchwood was separated from needles and discarded. Needles were easily stripped from branches after a few hours of drying at 100°C. The needles were again ovendried and weighed to determine the respective quantities of needles. The regression equations for branches up to 500 grams dry weight and from crown sections of five intensively sampled trees were as follows:

Crown position	Branches	Equation
	No.	
Lower	136	$\hat{Y} = 1.42 + 0.48X$
Middle	167	$\hat{Y} = 2.20 + 0.57X$
Upper	190	$\hat{Y} = 0.66 + 0.58X$

where $\hat{Y}$ was estimated dry weight of needles, and X was dry weight of needles plus branchwood in grams. Each of the above equations accounted for more than 95 percent of the total variation. The regression coefficient for the lower crown section indicated fewer needles per unit of branchwood, but was not significantly different from regression coefficients for the middle and upper crown sections.

The general applicability of the above equations for estimating dry weight of needles was tested by subjectively selecting one sample branch from each of 53 trees. A wide array of sizes was sampled; 15 of the branches (ovendried needles plus branchwood) weighed between 500 and 800 grams. The constants for the equation were similar to the ones shown above, and the regression accounted for 94 percent of the variation:

$$\hat{Y} = 0.87 + 0.48X$$

where $\hat{Y}$ was estimated dry weight of needles, and X was dry weight of needles plus branchwood.

Diameter vs. Length of Branches

Nondestructive estimates of branch weight are often required for growth and fuel-accumulation studies. In young forest stands, branch diameters and length of branch axes can be obtained relatively easily and repeated over time to provide an indirect method for estimating weight or weight changes of branches. Branch diameters are more easily obtained and the relation of diameter to weight of needles plus branchwood for 89 sample branches from Pingree Park is shown in figure 14. Branch diameter was related to weight for five trees at Foxpark in about the same manner as shown in figure 14.

There was little apparent change in diameter-weight relations for branches from various heights in the crowns. Although the data in figure 14 may not be generally applicable for trees taller than about 15 m for insect-damaged trees or for trees on all sites, they do indicate that individual weights of live branches can be quantified by nondestructive methods.

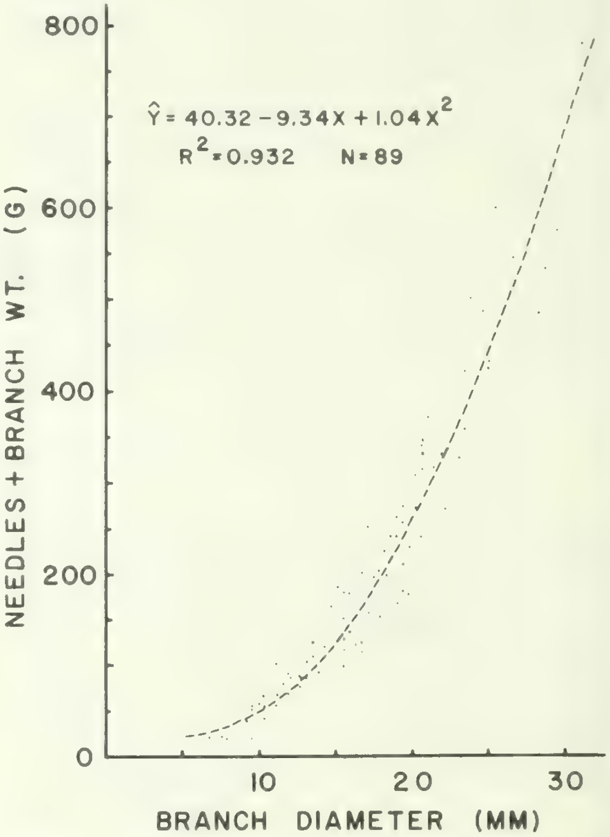

Figure 14.—The relation of branch diameters to dry weight of needles plus branchwood.

Distribution of Needles and Branch Weight

General observations of lodgepole pine and other conifers reveal both horizontal and vertical differences in the space distribution of needles and branches. Near the top of the crowns, the relative amounts of needles and branchwood are small due to the young age of the branches. In the midcrown region, the branches are larger, have more side branchlets, and support more needles. Below the midcrown region, needles and branch quantities are decreased by mortality, apparently because of decreasing light quality.

Weight Distribution Along Branches

The branches on two trees were studied to obtain better knowledge of the horizontal weight distribution of needles and branchwood. One tree had branches ranging up to 1.4 m in length; maximum lengths on the second tree were about 1.1 m. The sample unit consisted of all branches in an annual whorl. The average percent weight distribution of needles and branchwood was plotted as a function of 0.1-m increments of the branches (figs. 15, 16).

The average weight distribution of needles along the branches within all crown sections of both trees clearly indicated the expected region of low needle density near the bole. Needle concentration was maximum near the average midlength of the branches and in the zone of maximum branching. The arrow pointers in figure 15 show that 50 percent of the needle weight was usually reached near the midlength of the branches, which suggests a symmetrical "bell shape" or normal distribution pattern. In the upper crown sections of both trees, the region of highest needle concentration was nearer to the bole than in the middle and lower crown regions. The maximum weight percentage of the needles remained near the midlength of the shorter and younger branches, however, which had undergone little needle cast and secondary branching.

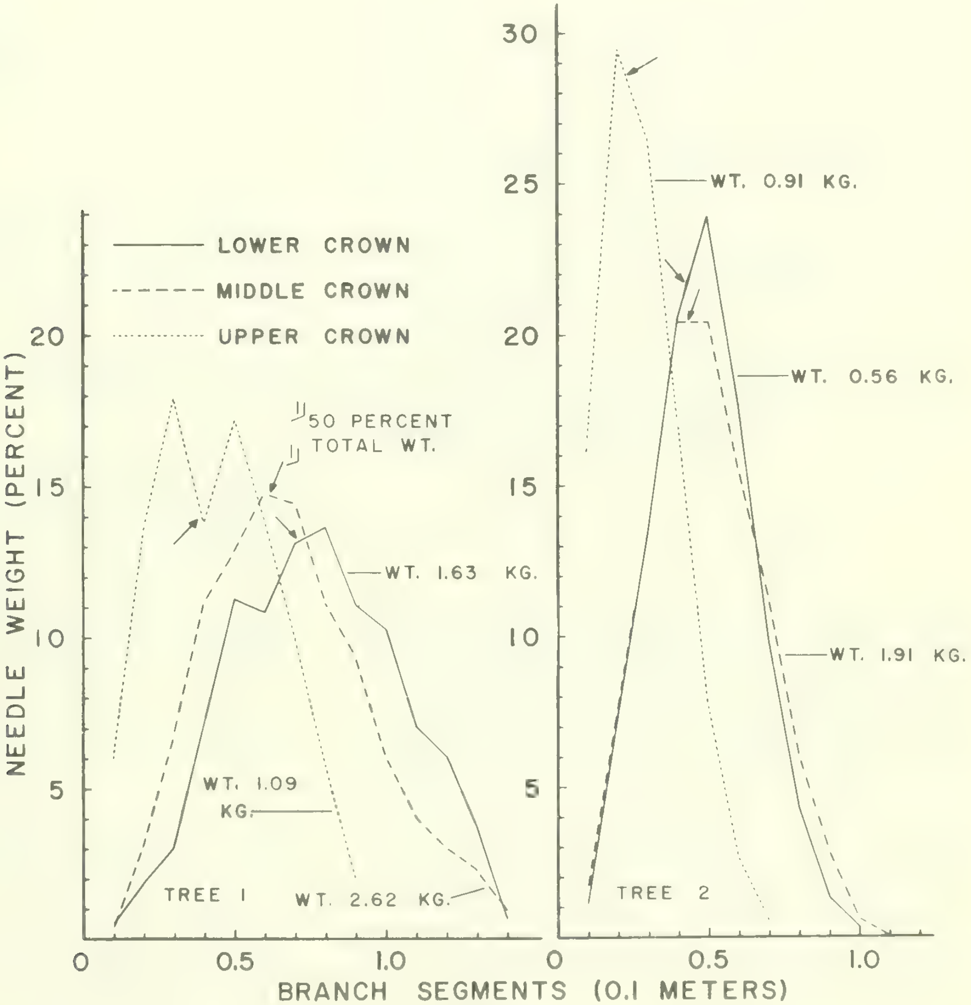

Figure 15.—Average horizontal weight distribution of needles along branches in three crown sections of two trees.

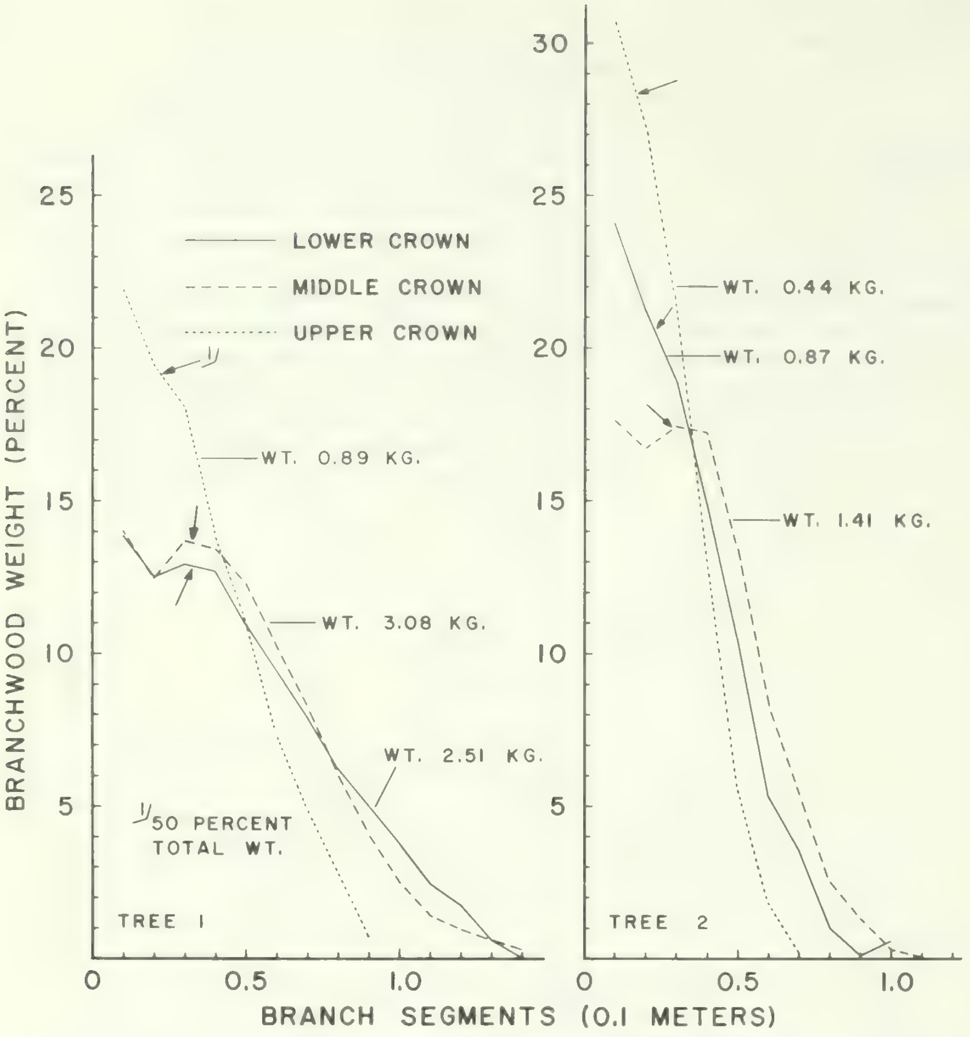

Figure 16.—Average horizontal weight distribution of branchwood in three crown sections of two trees.

The patterns of needle weight concentrations were about the same in both trees. However, the volume distribution of needles along and around the branches could not be quantitatively inferred from the weight distribution data. The distribution of needles on individual branches appears highly dependent upon variables such as light quality, position within the crown, competition for space from branches above and from neighboring trees, age and growth vigor of branches, and branching forms.

In contrast to needle weight distribution, average weights of the 0.1-m branchwood segments were highest near the bole and decreased steadily to the branch tips (fig. 16). The occurrence of secondary branching in the lower and middle crown regions was evidenced by the slight weight increase in the lower and middle crown sections of tree No. 1 and the middle crown section of tree No. 2. On the average, 50 percent or more of the branchwood weight in all crown sections was contained within the first 30 percent of the branch length.

Vertical Weight Distribution in the Crown

The variability of weight distribution associated with the lower, middle, and upper crown sections of 100 trees in the even-aged stand at Foxpark is shown in figure 17. The height range of the trees, which was relatively narrow, had little apparent effect on weight percentage distribution within the individual crowns. The coefficient of variation ($S/\bar{X}$) for crown weight (needles plus branchwood) percentages was highest in the upper crown sections, apparently the result of varying tree heights and branch sizes, and relative exposure and shading within the canopy. The

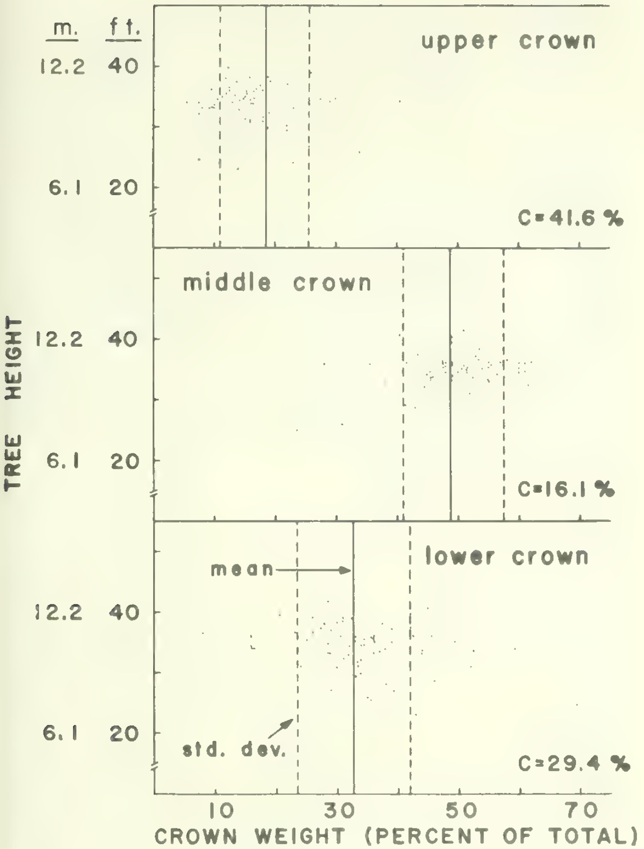

Figure 17.—Weight percentages of needles plus branches in the lower, middle, and upper crown sections for 100 trees.

average vertical distribution of needles plus branch weights within the crown sections followed a normal distribution curve. The general pattern was gradually increasing branch weight from the lower to midcrown region, and then more rapid decrease of weight from midcrown to the upper crown.

Since the stand canopy is the whole collection of crowns of various widths and lengths, it is usually of greater interest than the crowns of individual trees. The weight distribution within the canopy formed by a sample of 10 trees at Foxpark was computed by two empirical methods. The distribution of needle and branch weights was also compared to normal distribution curves. The ranges of heights and crown lengths for the 10 trees were previously illustrated in figure 4.

In the first method, live crown length of each tree was divided into 10 equal parts. Length of the crown segments varied from tree to tree. Weights of the branch whorls for each tree were then mathematically apportioned to the 10 crown height sections. The needle plus branch weights for similarly positioned crown height sections for each of the 10 trees were then summed. Average percentages of total weight were computed for each of the 10 crown height sections and plotted as to height in the average crown or canopy (fig. 18A).

In the second method, the canopy zone was assumed to start at the lowest all-live whorl and stop at the apex of the tallest tree. As previously seen in figure 4, the maximum lower and upper height limits of the canopy were on different trees. The canopy depth, based on the 10 crowns, was then divided into 10 equal height sections. Branch weights of the 10 trees were then mathematically apportioned according to relative height in the normalized canopy. The apportioned weights within each of the 10 sections of the canopy were summed, and percentages of total canopy weight computed (fig. 18B).

Both empirical methods of determining crown weight distribution agreed well with the observed values for crown weight percentages and the expected or theoretical frequencies of a normal distribution. Chi-square values for both methods showed probabilities greater than 30 chances out of 100; no real departure from normality was indicated. For the first method of average values (fig. 18A), the apparent canopy depth was compressed about 1.2 m on both the bottom and top. Averaging of branch weights for both short and long crowns indicated greater skew of weight distribution to the lower part of the canopy. The relative average canopy height at the point of theoretical maximum value for weight distribution was also about 60 cm lower than that observed for the lower-upper height range canopy method. The values in figure 18B apparently provided a better characterization of the canopy weight distribution, since the whole depth range (lower and upper height values) of the canopy was used.

Crown Weight Estimates

Crown weights are generally estimated by regression techniques that utilize measurements of bole diameters or branch diameters (Kittredge 1944, Loomis and others 1966, Madgwick 1971). Another good but seldom used method is to stratify branches into classes such as crown position, age, and size, and then select the median branch for weight estimation (Baker 1948).

Table 1 summarizes selected equations for the relation of crown weights (Y) to d.b.h. and other commonly measured stem and crown variables (X) for 117 trees at Foxpark. The equations with d.b.h. or diameter at start of live crown accounted for more sampling variation than the combined variables of tree height and crown length. As seen in table 1, including tree height (eq. 6) and crown length (eq. 5) with untransformed d.b.h. did not increase percent of variation accounted for. In Canada, Kiil (1971)

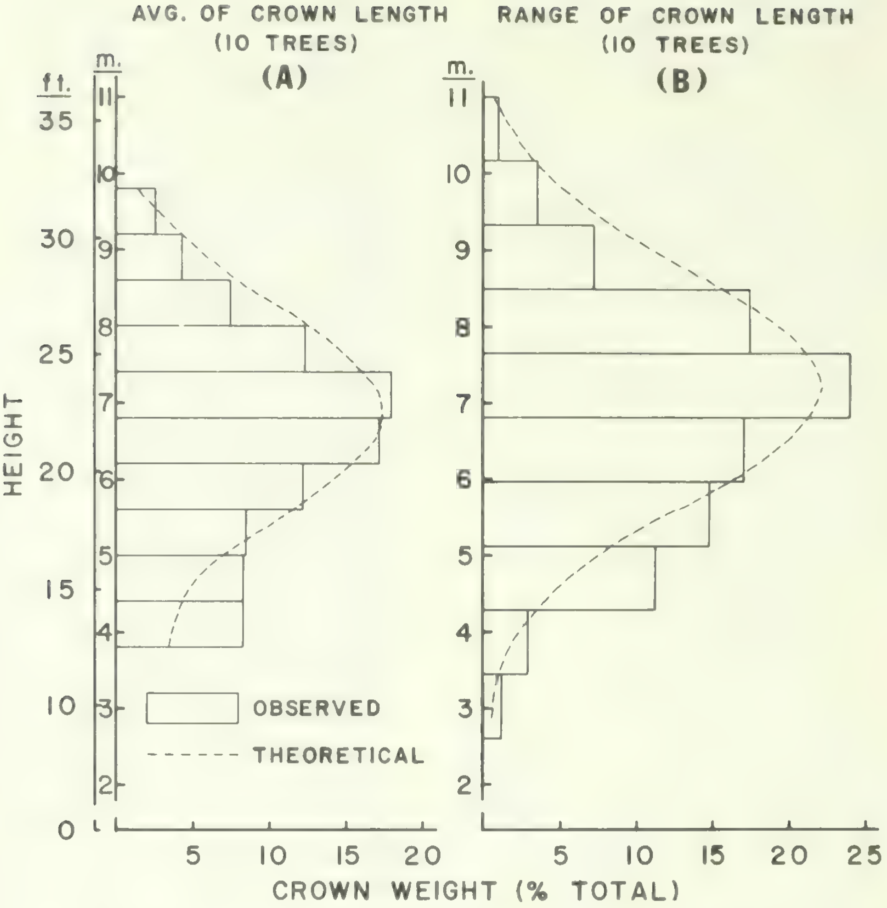

Figure 18.—Vertical weight distribution of needles plus branchwood for 10 height sections as computed for **(A)** average crown height, and **(B)** canopy averaged over maximum lower-upper height range of crowns.

Table 1.--Relation of total needles plus branchwood weight (Y), in kilograms, to selected items and crown variables (X) for 117 trees

Variables	Regression equations	Variation accounted for (R^2)
		Percent
D.b.h., X_1	(1) $Y = -10.594 + 1.528X_1$	78
Diameter, base live crown, X_2	(2) $Y = -8.727 + 1.656X_2$	78
Crown length, X_3	(3) $Y = -3.809 + 2.070X_3$	33
Tree height, X_4	(4) $Y = -17.672 + 2.538X_4$	44
D.b.h. × crown length, $X_1 \cdot X_3$	(5) $Y = -2.442 + 0.145\ (X_1 \cdot X_3)$	68
D.b.h. × tree height, $X_1 \cdot X_4$	(6) $Y = -5.204 + 0.105\ (X_1 \cdot X_4)$	74
D.b.h.^{2} × tree height, $X_1^2 \cdot X_4$	(7) $Y = -0.833 + 0.005\ (X_1^2 \cdot X_4)$	80
D.b.h. × d.b.h.^{2}, X_1^3	(8) $Y = +0.605 + 0.004\ (X_1^3)$	83
D.b.h. + d.b.h.^{2}, $X_1 + X_1^2$	(9) $Y = -3.300 + 0.154X_1 + 0.061X_1^2$	82
Log d.b.h., X_1	(10) $Y = +0.0047X_1^{2.916}$	91

established regression constants, and found that crown weights of lodgepole pine could be estimated from aerial photographs with the same degree of accuracy as tree heights and crown widths.

The allometric function (d.b.h.^{2} × tree height, or D^2H, eq. 7, table 1) only slightly improved the regression estimate over the single-variable d.b.h. equation. The formula D^2H, generally proportional to stem volume, is used worldwide for the estimation of biomass (Crow 1971).

Of the several variables used in table 1, the curvilinear function d.b.h.^{3} (eq. 8) accounted for 83 percent of sample variation, was slightly superior to the allometric function (eq. 7), and was more convenient to use because tree height was not required. All the single-variable equations with diameter as an independent variable were satisfactory for estimating total needle and branch weight of a crown. The logarithmic (base 10) transformation of d.b.h. (X) and needle plus branch weight (Y) best described the functional relationship, and accounted for 91 percent of the sampling variation (eq. 10).

The regression of dry weight of needles plus branches on d.b.h. for 117 trees was plotted with 95 percent confidence limits for individual and mean tree weights (fig. 19). A larger range of tree diameters would perhaps narrow the confidence bands and decrease the variance for crown weight estimates. The figure also demonstrates high correlation between diameter and weight, and the reliability of d.b.h. for predicting crown weights.

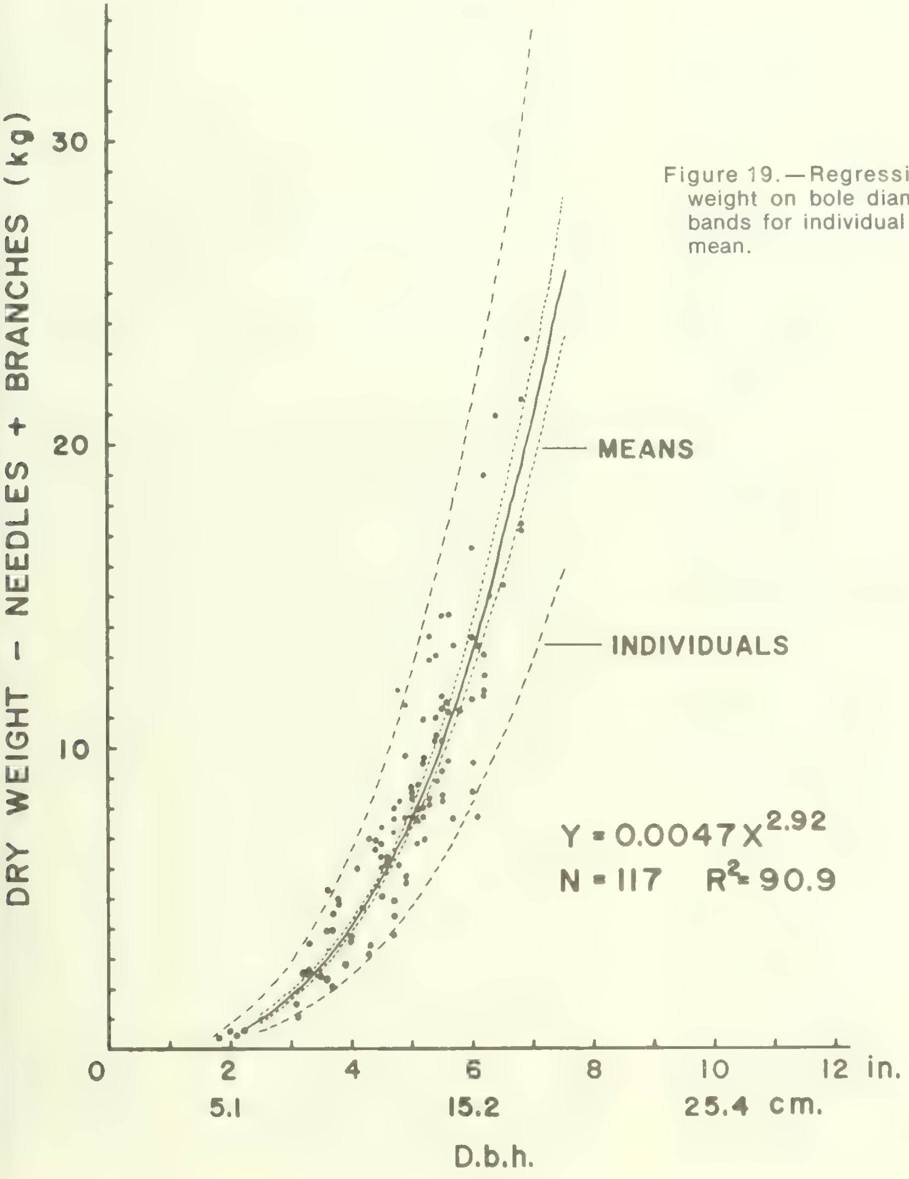

Figure 19.—Regression of needle-plus-branchwood weight on bole diameter, with 95 percent confidence bands for individual observations and the population mean.

SUMMARY AND CONCLUSIONS

The horizontal and vertical distribution of needles and branches, their quantities, and their interrelations must be better understood if we are to manage our forests for maximum production of wood fiber. This study reports various relationships between needles, branch components, and boles for 298 trees, and methods of estimating biomass from these relationships.

Height to live crown averaged about 4.6 m for all trees. The crown length to height ratio was 0.58 at Foxpark, 0.66 at Pingree Park, and about 0.35 in the "dog hair" stand. Crown length was weakly correlated with d.b.h. and tree height; it was apparently more dependent upon spacing and light.

Individual branches per annual whorl ranged from 1 to 8, and averaged about 4. Average length or axis for 493 live branches on five trees at Foxpark was 46 cm, and maximum length was about 1.5 m. Total length of individual branches averaged about three times greater than their axes.

Analysis of variance indicated no significant departure from radial symmetry in branch numbers or among directional quadrants within lower, middle, and upper crown sections for two study trees. Branch angles were steeper in the upper crowns. Older branches in the lower and middle crown sections had lower angles and were succeedingly influenced by annual weight increments, and branch tips were reflexed upward.

There was an apparent trend of decreasing weight of individual fascicles from the top to the bottom of the crown. The current year, 1-, and 2-year-old needle age classes each accounted for 10 to 14 percent of the total weight of needles. Needles 3 years and older accounted for about 62 percent of total needle weight.

For one 13-cm-diameter, 13.2-m-tall tree, about 50 percent of the cumulative branch surface area and about 42 percent of the needle surface area was in the lower half of the crown. Total surface area was about 42.5 m^2 for needles, 6.4 m^2 for crown branches, and 2.6 m^2 for the crown bole section.

Weights of needles and branches were very useful for obtaining information on component relations within the crowns of felled trees. Weighing was practical because the moisture content of branches did not vary significantly from the bottom to the top of the crowns, and thus, there was excellent correlation between green and ovendry weights. The regression of green weight on dry weight usually accounted for 95 percent of the sampling variation. When weights of needles and branches were estimated indirectly from branch diameters, regression equations showed that about 90 percent of the sampling variation was accounted for.

Except in the upper crown sections, there were relatively few needles near the bole. Maximum needle concentrations were near the midlength of the branches and/or in the zone of maximum branching. Generally, needle weight was normally distributed along the length of branches in the lower and middle crown sections. In the upper crown sections, higher needle concentrations near the bole were due mainly to younger branches which had undergone little needle cast or secondary branching.

On the average, more than 50 percent of the weight of branchwood was contained in the first 30 percent of branch length for all crown sections.

Crown weight (needles plus branchwood) for a sample of 100 trees gradually increased from the lower to midcrown region, and then decreased through the upper crown region. The vertical weight distribution of needles and branches through the canopy of 10 intensively studied trees was symmetrical and followed a normal distribution curve. Once the constants for characteristic normal distribution curves are established for lodgepole pine, it should be possible to characterize the canopy over large areas by various indirect methods. One indirect method relates the mass of needles and branches to reduction in windspeed ratios for various heights in a canopy (Cionco 1972).

Weights of entire crowns were estimated from the regression of weight on several combinations of easily measured variables. Equations with d.b.h. accounted for more sampling variation than both tree height and crown length. Logarithmic transformations of d.b.h. and crown weight best described the functional relationship, and accounted for 90 percent of the sampling variation.

The major problems in measuring needles and branchwood result from the great diversity within and between trees. Thus "the most accurate sampling methods would be to sample a large number of trees covering the size range present in the stand and determine regression equations relating dry weight . . . to certain linear dimensions" (Ovington and Madgwick 1959). Not all available data were used in quantifying relationships in the present study, nor were all possible combinations of the variables reported. The high correlations found between the various needle and branch variables strongly indicate that many indirect and nondestructive techniques can be used to quantify changes in both short- and long-term structure and productivity for one tree or for a whole stand. Nondestructive dimensioning systems and techniques will require calibration against some easily measured tree variable for the range of expected tree sizes.

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Gross dimensions and quantities of needles and branches are presented for 298 trees. Weight, diameter, length, and height relations were usually highly correlated. Needles were normally distributed along the length of branches as well as vertically through the canopy. Needle and branchwood weights for entire crowns were best estimated by the logarithmic transformation of diameters at breast height.

Keywords: *Pinus contorta,* biomass, canopy, foliage, overstory productivity, transpiration.

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